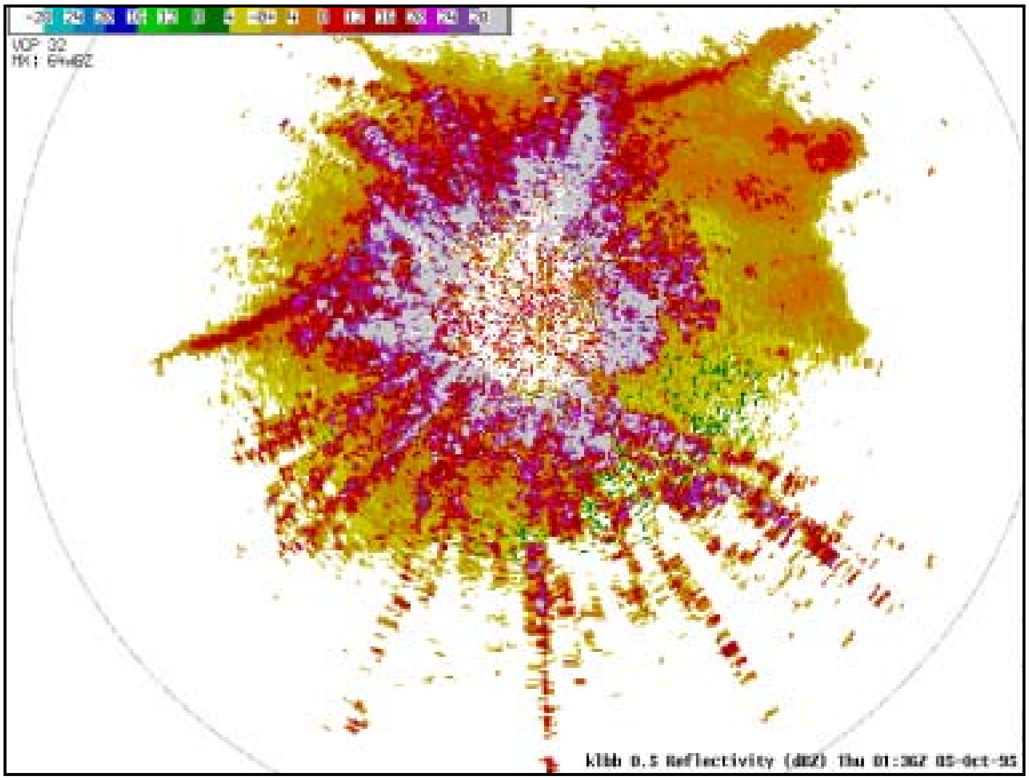
Distance Learning Operations Course



Instructional Component 5.3: Principles of Meteorological Doppler Radar

Presented by the
Warning Decision Training Branch

Version: 0307

Precipitation Estimation

This section will discuss how the WSR-88D estimates precipitation rate, R, from reflectivity, Z, and the sources of potential error in relating Z to R. You will also learn to determine whether radar- or rain gage-derived precipitation estimates are more appropriate in a given situation.

Objectives

Without references and in accordance with the lesson, you will

1. Identify how reflectivity factor, Z, and rainfall rate, R, depend on drop-size distribution and the resultant limitations on relating R to Z.

2. Identify 3 of 10 potential error sources (discussed in class) associated with radar rainfall measurements.

3. Identify the precipitation estimation method most appropriate for a given meteorological situation.

Reflectivity, Z and Rainfall Rate, R (Objective 1)

Reflectivity - Z

Though reflectivity, Z, is estimated from returned power, Z could be calculated directly if the drop-size distribution was known.

Reflectivity depends on the dropsize distribution as follows:

$$Z = \int N(D) D^6 dD$$

Where

Z = reflectivity factor
D = drop diameter
N(D) = number of drops of given diameter per cubic meter

Z dependent on sixth power

Z is dependent on the dropsize distribution, in particular the ***sixth power*** of the drop diameter.

Sample Z computation

Suppose the radar samples a cubic meter of air which contains 729 one millimeter drops and one three millimeter drop.

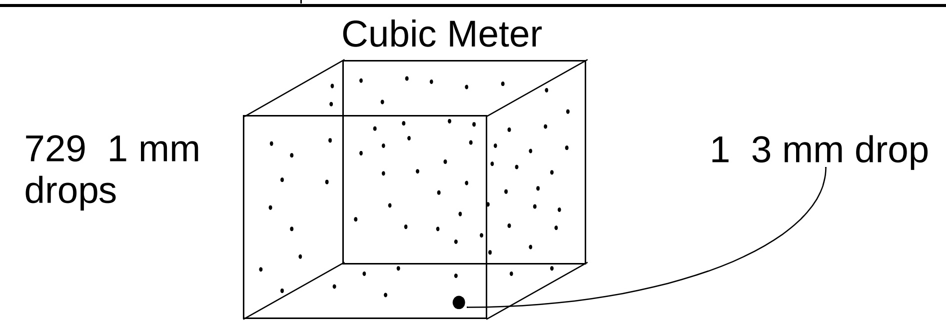


Figure 1. Sample Z computation.

Using the above equation for Z

$$\begin{aligned} Z &= (729\ \text{drops/m}^3)(1\ \text{mm})^6 + (1\ \text{drop/m}^3)(3\ \text{mm})^6 \\ &= 729\ \text{mm}^6/\text{m}^3 + 729\ \text{mm}^6/\text{m}^3 \\ &= 1458\ \text{mm}^6/\text{m}^3 \end{aligned}$$

For Z = 1458 mm^6/m^3, result is 32 dBZ

Z converted to dBZ

Because of its extremely large range of values (zero to 1,000,000+), Z is rarely used in operational meteorology. Instead, it is converted to dBZ by dBZ = 10 log Z. Hence, dBZ = 10 log 1458 ≈ 10(3.16) ≈ 32 dBZ.

The contribution to total reflectivity from the ***single*** three millimeter drop equals that of ***all*** 729 one millimeter drops. This dramatically illustrates the dependence of reflectivity Z on the sixth power of drop diameter. Minor changes in the drop diameter cause very large changes in the reflectivity.

Estimating Z

Reflectivity, Z, could be computed directly if the dropsize distribution was known. However, radars can only measure returned power. Z is then estimated via the Probert Jones radar equation. A problem arises because different dropsize distributions can generate identical Z values, and this will affect the accuracy of the precipitation estimate.

Rainfall Rate - R

Rainfall rate, R, is dependent on the dropsize distribution, but differently than Z. R is also dependent on the fall velocity of the drops, w_t, which depends on the diameter of the drops. This relationship is:

$$R = \frac{\pi}{6}\int N(D)D^3 w_t(D)dD$$

Where

R = rainfall rate
D = drop diameter
N(D) = number of drops for a given diameter per cubic meter
$w_t(D)$ = fall velocity for a given diameter

R dependent on third power

Note that R is dependent on the ***third*** power of the drop diameter.

Sample R computation

Using the above summation for rainfall rate, with $N(D) = 600$ drops/m^3, D = 1 mm, and w_t = 4 m/s,

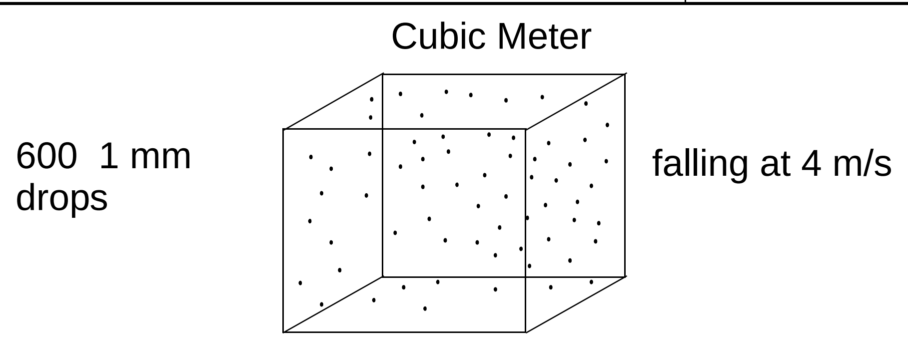


Figure 2. Sample R computation.

$$\begin{aligned} R &= (\pi/6)(600/m^3)(1\ mm)^3(4\ m/s) \\ &= (\pi/6)(600/10^9\ mm^3)(1\ mm^3)(4000\ mm/s) \\ &= (0.0004)\pi(mm/s) \end{aligned}$$

≈ 0.00127 mm/s

Converting to inches/hr,

$= (0.00127 \text{ mm/s})(\text{inch}/25.4 \text{ mm})(3600 \text{ s/hr})$

$R = 0.18$ inch/hr.

Same Z, Different R

Consider two volumes of air with the same reflectivity but with different rainfall rates.

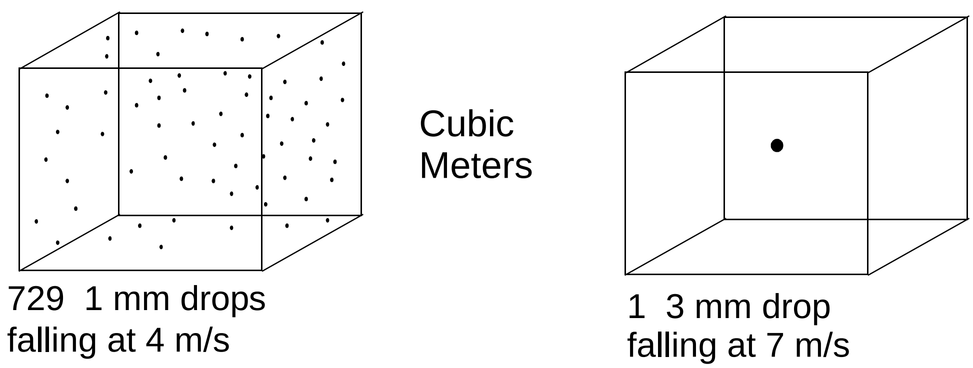


Figure 3. Same Z, different R.

In Figure 3, the first volume contains 729 1 mm drops which fall at 4 m/s. On page 2, we found that $Z_1 = 729$ mm^6/m^3 which converts to 29 dBZ. For volume 1, ***R_1 = .22 inch/hr***. The second volume contains a single drop with diameter of 3 mm which falls at 7 m/s. On page 2, we found that this single 3 mm drop also has $Z_2 = 729$ mm^6/m^3 or 29 dBZ. However, for volume 2, ***R_2 = .01 inch/hr***.

Though ***Z is the same***, the ***rainfall rates*** of the two volumes are ***significantly different***.

Same R, Different Z

Conversely, two volumes may have the same rainfall rates but different reflectivity.

In Figure 4, the first volume contains 600 1 mm drops falling at 4 m/s. We find that $R_1 = .18$ inch/hr, and ***Z_1 = 600 mm^6/m^3 or 28 dBZ***. The second volume contains only 50 2 mm drops falling at 6 m/s. $R_2 = .18$ inch/hr, but ***Z_2 = 3200 mm^6/m^3 or 35 dBZ***, more than 5 times greater than the first sample.

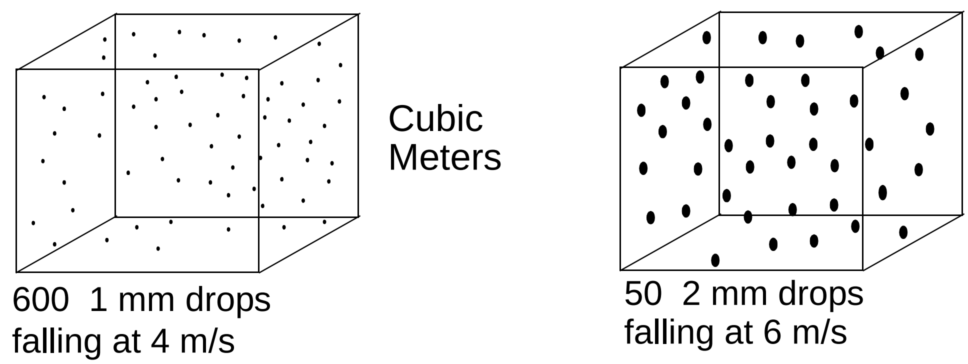


Figure 4. Same R, different Z.

Interim Summary

Z-R relationship not unique

Z is proportional to the ***sixth*** power of drop diameter, while R is proportional to the ***third*** power of drop diameter. Hence, ***the Z-R relationship is not unique*** because, for a given Z, many R values are possible. Likewise, for a given R, many Z values are possible.

R estimated from Z

The average returned power from a range bin is calculated, then Z is determined from the short form of the radar equation. ***R can then be estimated from Z*** through a Z-R relationship.

WSR-88D Z-R Relationships

There are several Z-R relationships that can be used, depending on the type of rainfall event. By editing the Z-R adaptable parameters, different Z-R relationships can be employed as needed. It is important to remember that whichever Z-R relationship is chosen, we are attempting to assess the rate of ***liquid*** precipitation.

Convective Z-R Relationships

There are two Z-R relationships available for convective situations. The first is intended for summertime deep convection, as well as general non-tropical convection. This relationship is:

$$Z = 300R^{1.4}$$

The second convective Z-R relationship is intended for tropical and subtropical events, which tend to have large numbers of smaller drops. This relationship is:

$$Z = 250R^{1.2}$$

Stratiform Z-R Relationships

There are three Z-R relationships available for stratiform situations. The first is intended for any general stratiform precipitation event, and it is the well known Marshall-Palmer Z-R relationship:

$$Z = 200R^{1.6}$$

The two remaining stratiform Z-R relationships are intended for winter events (still rain, not snow!), as well as orographic rain. The first winter stratiform Z-R relationship is intended for areas east of the continental divide:

$$Z = 130R^{2.0}$$

The second winter stratiform Z-R relationship is intended for areas west of the continental divide:

$$Z = 75R^{2.0}$$

Coordination

The ability to choose among several Z-R relationships has an impact on the accuracy of the rainfall estimates for each WSR-88D. Since there are many users of the data for any particular WSR-88D (RFCs, other WFOs, DOD, FAA, media, etc.), coordinating the Z-R relationship choice may be necessary from time to time.

Errors

Choosing an appropriate Z-R relationship can certainly enhance the accuracy of rainfall estimates. However, there are many other sources of errors when using radar estimated rainfall, which will follow in the next objective.

Error Sources in Radar Estimated Rainfall (Objective 2)

Types of errors

Several potential errors may affect the estimation of R in the WSR-88D. We will discuss three types of errors, five Z estimate errors, two Z-R relationship errors, and three below-beam effect errors.

Z estimate errors

1. Ground clutter

Ground clutter is power returned from ground targets. If these power returns are not removed by filters and are input to the Z-R equation, rainfall amounts within the ground clutter area will be overestimated. If, however, ground clutter filtering is performed in areas where no ground clutter exists, some power from true meteorological targets could be removed resulting in underestimated rainfall amounts in that area.

2. Anomalous propagation (AP)

Anomalous propagation (AP) is a term that technically refers to the propagation of the radar beam, though it is used to describe the features on radar images. Specifically, the beam is superrefracting and hitting the ground at some distance from the RDA. Hence, AP is really ground clutter at varying distances from the RDA. If not filtered out, these ground returns will be included in the Z-R equation and, just like normal ground clutter, will cause precipitation to be overestimated. If filtering for AP is performed in areas where no AP is occurring, precipitation will be underestimated.

3. Partial beam filling

Partial beam filling usually becomes a problem with meteorological targets distant from the radar. At 100 miles from the RDA, the WSR-88D's 1° wide beam is nearly two miles across. One of the radar equation assumptions is that a target's hydrometeors uniformly fill the radar beam. Thus, a target at a range of 100 miles that is narrower than the beam will be displayed as larger in area than it really is. The power return from this smaller target is averaged over the entire beam width, resulting in an underestimated rainfall rate.

4. Wet radome

If the radome is wet because of heavy rain or partially frozen precipitation, the radar will underestimate rainfall rates from targets away from the RDA because the power in the beam is attenuating close to the RDA. Less power to the target means underestimated reflectivity and rainfall rates.

5. Incorrect hardware calibration

Incorrect hardware calibration will cause significant errors in the rainfall estimate. The WSR-88D calibrates itself every volume scan, resulting in more accurate reflectivity and, hence, rainfall estimates. A quantity, ***Delta Sys Cal*** (Delta System Calibration), indicates the amount of calibration in dB the radar is executing each volume scan. When this value reaches ±2 dB, ***maintenance is required***. When this value reaches ±4 dB, ***maintenance is mandatory***. Delta Sys Cal is part of the NEXRAD Unit Status product at AWIPS. Large fluctuations in Delta Sys Cal from one volume scan to the next indicate hardware malfunctions. Z and, therefore, R may be overestimated or underestimated.

Z-R relationship errors

There are two potential error sources related to the Z-R relationship.

1. Variations in drop-size distribution

Variations in drop-size distribution from that assumed by the Z-R equation can cause either an overestimate or an underestimate. Different drop-size distributions can produce the same Z value, but result in rainfall rates (R) that may be significantly different from the rate (R) in the Z-R equation.

2. Mixed precipitation

When rain is mixed with hail, snow, or sleet, large reflectivity values result, causing overestimation of rainfall rates.

Bright band

As ice crystals fall through the melting level their outer surface begins to melt. Just below the melting level (0° C surface), these water coated ice crystals are highly reflective, producing enhanced radar signatures with an arc-like structure. This feature, called the “bright band” because of its appearance on radar images, will cause overestimation of rainfall rates.

Below beam effect errors

1. Strong horizontal winds

Strong horizontal winds below the cloud base will displace the rainfall away from the ground below the range bin being sampled, to below a totally different range bin.

Strong horizontal winds-overestimate or underestimate?

In Figure 5, the radar estimates 50 dBZ in the storm core, directly above rain gage A. Strong winds below the cloud are blowing the rain away from gage A into gage B some distance downwind. The problem is that the radar is estimating 0 dBZ in the range bin above gage B. The radar shows zero rainfall for the area above gage B, when the gage shows significant rainfall.

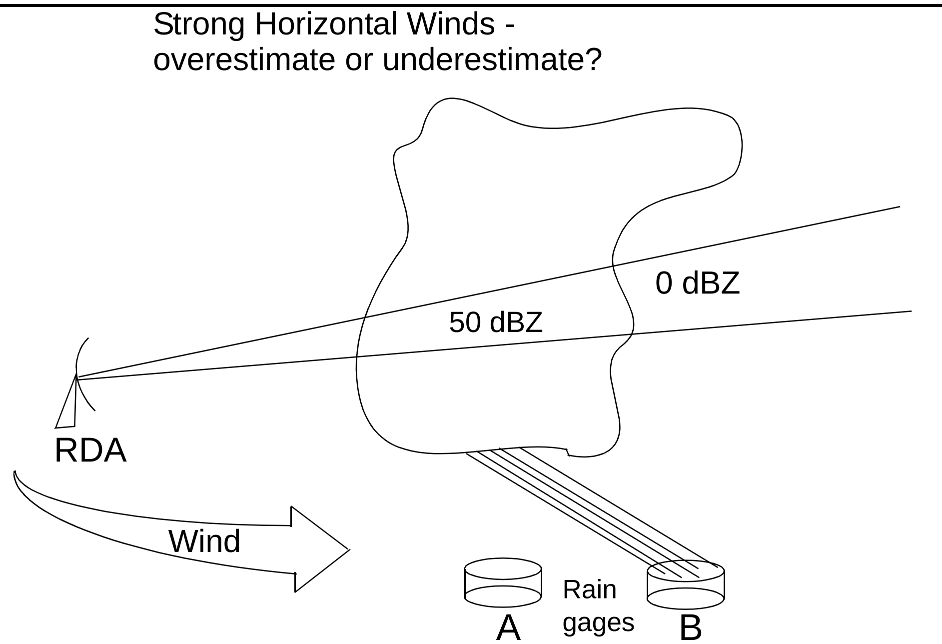


Figure 5. Effects of strong horizontal winds below the beam.

2. Evaporation below the radar beam

Evaporation below the radar beam will cause the radar to overestimate how much rain is actually falling on the ground. The extreme example is virga, where the radar estimate in the cloud is relatively accurate, but little or no rain is reaching the ground. This happens frequently in parts of the West.

3. Coalescence below the radar beam

Coalescence below the radar beam is most likely in tropical regions, but happens in many areas of the continental U.S. The radar underestimates rainfall rates because the numerous small drops of the tropical airmass being sampled by the radar beam begin sticking together as they fall below the beam. At long ranges, the highest dBZ values often occur in portions of the storm below the beam. Also at long ranges, even the ***lowest*** elevation scan can overshoot storm cores.

Radar Estimates vs. Rain Gages (Objective 3)

Situations will arise when it is better to rely more on the radar to estimate rainfall, or when the rain gages are better than the radar.

Scenarios

In the following scenarios, determine which rainfall estimation method (radar or rain gage) is better. In the space after “Significance”, describe how that element of the scenario affects your decision.

Scenario 1

1. Isolated convective storms within 60 nm of the RDA. Significance:

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____

2. No hail reports. Significance:

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____

3. No significant winds, evaporation, or coalescence below the beam. Significance:

____

____

Radar or rain gage estimate better?

____

____

Scenario 2

1. Stratiform precipitation over a large area. Significance:

____

____

2. Occasional wet snow reports, though most precipitation liquid. Significance:

____

____

3. Ground temperatures above freezing. Significance:

4. Freezing level at about 3000 feet AGL. Significance:

Radar or rain gage estimate better?

Scenario 3

1. Large area of widely scattered showers and thunderstorms within 60 nm of the RDA. Significance:

2. Several reports of ice pellet showers. Significance:

3. Cells persist several hours with little movement. Significance:

4. Late evening event. Significance:

Radar or rain gage estimate better?

Precipitation Estimation Review Exercises

1. Is it possible to derive a unique expression relating R to Z? Why or why not?

2. Among the possible error sources associated with radar rainfall estimates:

a. Which Z estimate error(s) could cause either an *overestimate* or an *underestimate* of precipitation?

b. List two factors that affect the validity of a Z-R relationship.

3. Which of the following are below beam effects that would cause the WSR-88D to *underestimate* rainfall?

a. strong horizontal winds displacing precipitation away from the ground below the beam
b. strong horizontal winds displacing precipitation from an adjacent shower onto the ground below the beam
c. evaporation below the beam
d. presence of a strong updraft and hail

4. Describe a meteorological event where you would expect rain gage data to be more reliable than radar estimated rainfall.

5. Describe a meteorological event where you would expect radar estimated rainfall to be more reliable than rain gage data.

Signal Processing

The WSR-88D provides three types of base data, Reflectivity, Velocity and Spectrum Width. As these data are the input for the generation of radar products, it is important that the base data be of the highest possible quality. There are data quality issues inherent in meteorological Doppler weather radars. Proper interpretation of the WSR-88D products requires an understanding of data quality, and this section lays the necessary foundation for this understanding.

Objectives

Without references, and in accordance with the lesson, you will

1. Compute the radial velocity of a target given the radar viewing angle, actual target velocity, and the appropriate equation.

2. Identify how Doppler information is obtained by the WSR-88D to determine atmospheric motion.

3. Compute the ***speed*** a radar initially assigns a range bin, given a pulse-pair phase shift and a maximum unambiguous velocity (V_{max}).

4. Determine whether apparent target motion is ***toward*** or ***away*** from the radar, given **I** and **Q** values from two successive returned pulses.

Radial Velocity (Objective 1)

Radial velocity is defined simply as the component of target motion ***parallel*** to the radar radial (azimuth). It is that component of a target's motion that is either ***toward*** or ***away*** from the radar site along the radial.

Key points about radial velocity

Some important principles to remember about Doppler radial velocity are:

1. Radial velocities will always be ***less than or equal to*** actual target velocities.

2. ***Actual velocity*** is measured by the WSR-88D ***only*** where target motion is ***directly toward*** or ***away from*** the radar.
3. ***Zero velocity*** is measured where target motion is ***perpendicular*** to a radial or where the target is stationary.

The relation of actual velocity to radial velocity

When sampling large-scale atmospheric flow, most of what is depicted will be less than the actual environmental flow. The same holds true even for storm-scale rotational flows since only that component of a circulation either directly toward or away from the radar will have its actual velocity detected.

Radial Speed Equation

The relationship between a target's actual velocity and the WSR-88D depicted radial velocity can be described mathematically by using the Radial Speed Equation

$$|\boldsymbol{V_r}| = |\boldsymbol{V}| \cdot \cos\beta \qquad (1)$$

where:

- V_r = radial velocity
- V = actual velocity
- β = smaller angle between **V** and the radar radial
- cos = cosine

The angle β (beta) is ***always the smaller*** of the two angles between the radar viewing angle (i.e. radar radial or azimuth) and the actual target velocity vector (***V***).

β is equal to 0°

When β is equal to 0°, target motion is parallel to the radar beam and cos β is 1. The target radial

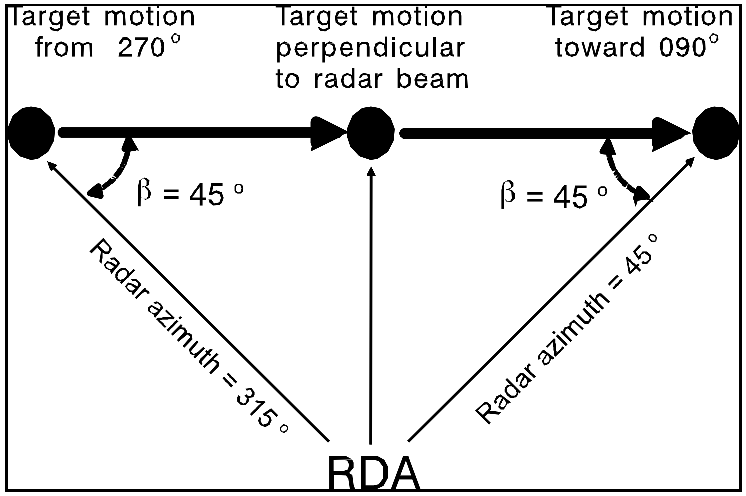


Figure 6. As target motion becomes more (less) perpendicular to the radar beam, β increases (decreases). When the target motion is exactly perpendicular to the radar beam β is 90° and the radial velocity is zero.

speed ($|V_r|$) is equal to the actual target speed ($|V|$).

β is equal to 90°

When β is equal to 90°, target motion is perpendicular to the radar beam and cos β is zero. The radial speed ($|V_r|$) is zero, and there is no component of target motion toward or away from the radar.

Radial velocity computation example

Assume that the actual wind is uniform from a direction of 300° at 30 knots through the lower atmosphere across the entire observational range of your WSR-88D (Figure 7).

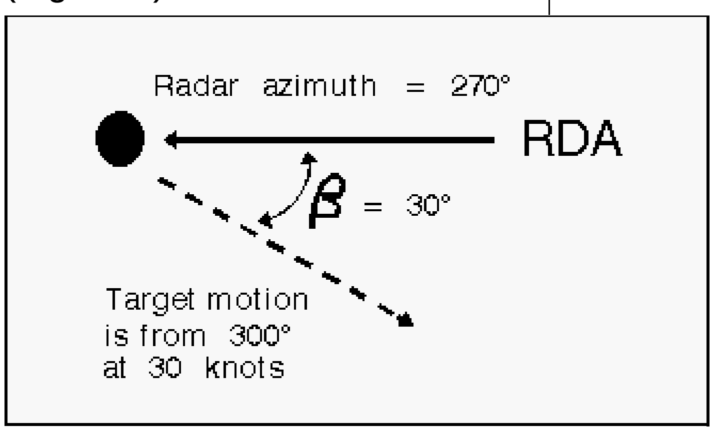


Figure 7. Radial speed computation example.

As the antenna is pointed due west (along the 270° radial), a radial wind speed of 26 knots would be measured. This answer is obtained by using equation (1) and β= 30°.

$$| V_r | = | V | \cos \beta$$
$$| V_r | = (30 \text{ kt}) \quad \cos (30°)$$
$$| V_r | = (30 \text{ kt}) \; (.866)$$
$$| V_r | = \quad 25.98 \text{ kt} \approx 26 \text{ kt}$$

Target direction

Once the speed is calculated from equation (1), the direction, inbound or outbound, must be determined. This is simply the direction of the component of the actual wind that lies along the radial. In Figure 7, the radial component, V_r, would be inbound toward the RDA. Thus the radial velocity is -26 knots.

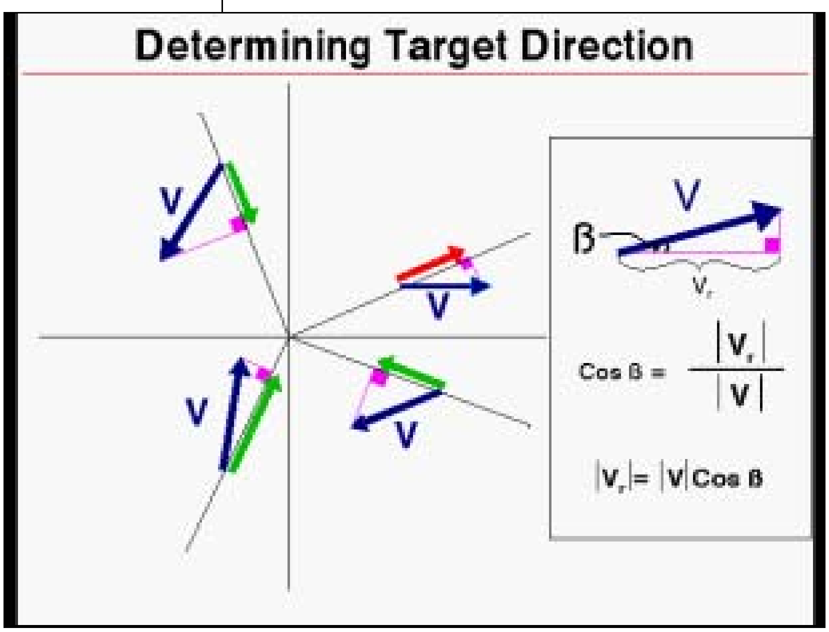


Figure 8. Determining the direction of the radial component of the actual velocity.

Relationship between β and percentage of actual velocity

The ***greater*** the angle between the target's velocity vector and the radar azimuth, the ***smaller*** the percentage of the target's actual velocity that will be measured and depicted on the Velocity products. Table 8 shows the relationship between β

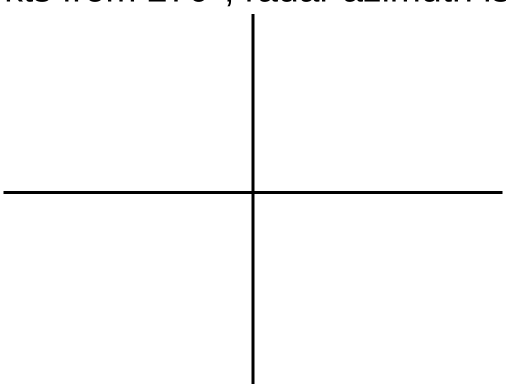
and what percentage of actual target speed is directly measured.

Table 8: Percentage of Target Speed Measured

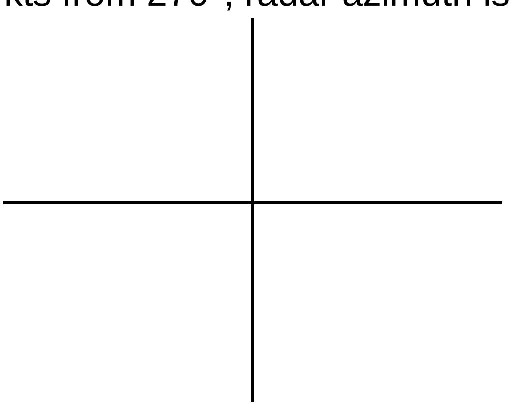
β degrees	Cosine β	Percent Measured
0	1	100
5	.996	99.6
10	.985	98.5
15	.966	96.6
30	.866	86.6
45	.707	70.7
60	.500	50.0
75	.259	25.9
90	0	0

Examples

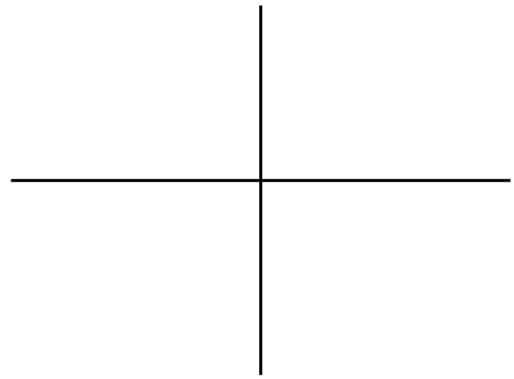
1. V = 40 kts from 270°, radar azimuth is 315°.



2. V = 40 kts from 270°, radar azimuth is 60°.



3. V = 50 kts from 360°, radar azimuth is 165°.



The Doppler Effect (Objective 2)

The Doppler Effect is defined as “the change in frequency with which energy reaches a receiver when the receiver and the energy source are in motion relative to each other” (from the Glossary of Meteorology). Determining the Doppler Effect or shift is straightforward when the energy transmission source is stationary and the target being sampled is moving (or stationary). Any frequency shifts would be solely the result of the target moving toward or away from the energy transmission source.

From basic physics, there is a relationship between the speed of transmitted electromagnetic (E-M) energy and the frequency and wavelength of that energy. This relationship is expressed as

$$\mathbf{c} = \mathbf{f}\lambda \qquad (1)$$

where **c** is the speed of light (assumed to be constant), **f** is the frequency and λ is the wavelength of the energy. If the wavelength (λ) is increased, the frequency (**f**) must decrease since the speed (**c**) is constant and vice versa.

If equation 1 is allowed to represent the Doppler motion of a target sampled by a weather radar, one would expect it to become

$$\mathbf{V}_r = \mathbf{f_{dop}}\lambda \quad \text{or} \quad \mathbf{f_{dop}} = \frac{\mathbf{V_r}}{\lambda} \qquad (2)$$

where $\boldsymbol{V_r}$ is the target's radial velocity, $\boldsymbol{f_{dop}}$ is the ***Doppler frequency shift due to target motion either toward or away from the radar***, and λ is the wavelength of the transmitted energy. For a stationary target, there will obviously be no wavelength or frequency change (Figure 9).

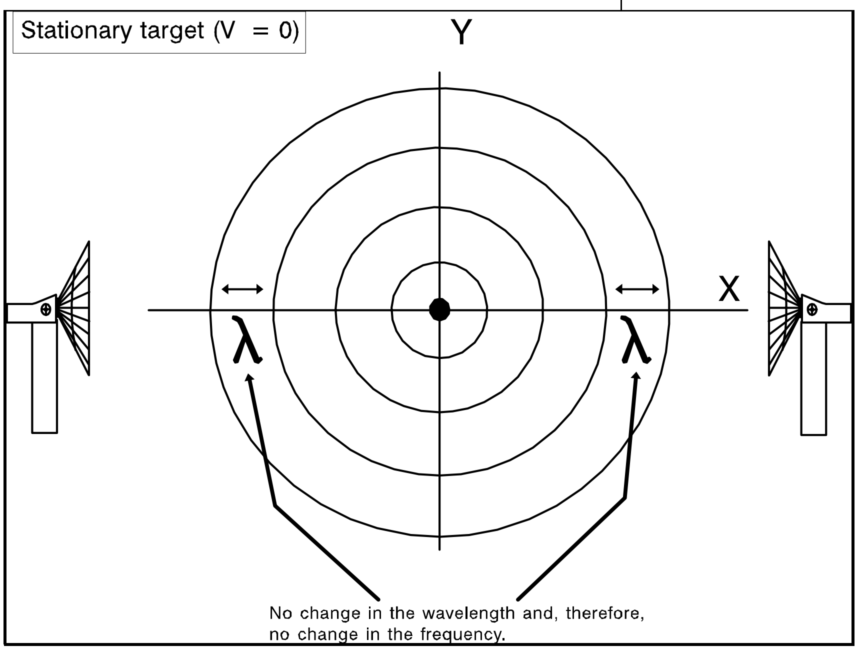


Figure 9. A stationary target has no frequency shift.

For a moving target, the amount of frequency shift due to motion toward or away from the radar will be the same, except that the sign will be different (Figure 10):

- shift is positive if the target is moving toward the radar
- shift is negative if the target is moving away from the radar

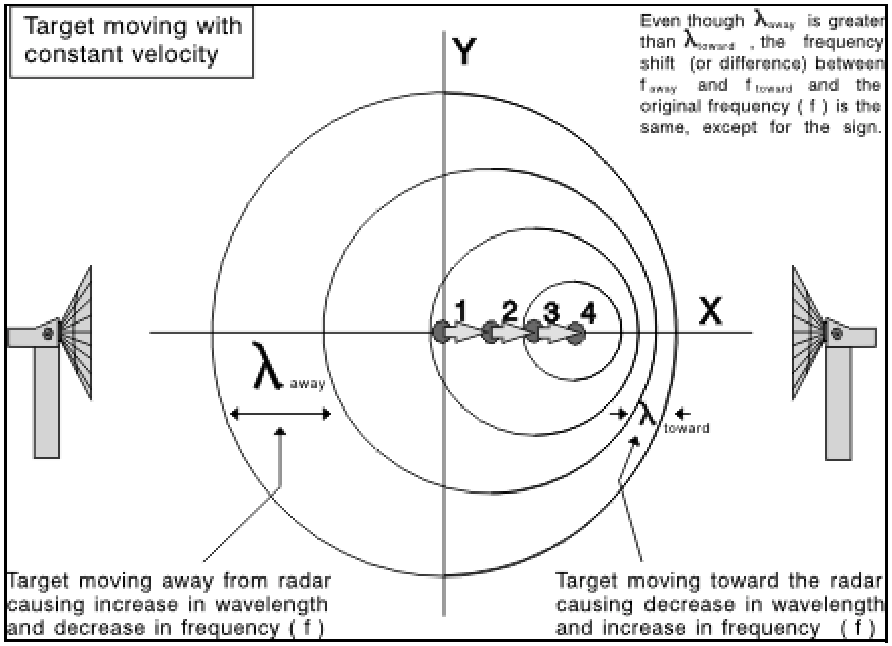


Figure 10. A moving target has a frequency shift.

However, in its present form, equation (2) will not yield the true velocity of a target. In the case of meteorological Doppler radar, the equation is

$$f_{dop} = \frac{-2V_r}{\lambda} \qquad (3)$$

The physical explanation for doubling the frequency is due to two factors: (1) the target's electric vibrational frequency increases by an amount equal to V_r/λ and (2) the frequency of the target's radiation field in the direction of the radar receiver is also increased by the amount V_r/λ (Doppler Radar and Weather Observations, Doviak and Zrnic, 1984). The negative sign is included to account for target motion toward or away from the radar (i.e. a negative V_r produces a positive f_{dop} and vice versa).

Equation (3) illustrates the ***direct*** relationship between the Doppler frequency shift and the radial velocity.

Sound wave example

The Doppler Effect is usually demonstrated using sound waves. An example would be when an emergency vehicle with its siren blaring is travelling toward you at a fairly high rate of speed. The increase in the sound pitch (frequency) is due to the compression (shorter wavelength) of the waves. As the vehicle moves away from you, the sound pitch (frequency) is decreased due to the expansion (longer wavelength) of the waves.

The frequency of a typical sound wave is 1×10^4 Hz (10,000 Hz). In a case where the source is moving at 50 knots toward or away from the receiver, a Doppler frequency shift of ~800 Hz would occur. That amount of frequency shift is ~8% of the ***original*** transmitted frequency. This can be easily measured, even by the human ear!

WSR-88D example

E-M waves transmitted by the WSR-88D are of a much higher frequency than sound waves and travel at the speed of light. For a Doppler radar using a wavelength of ~10.5 cm, the transmission frequency is $\sim 2.85 \times 10^9$ Hz (2.85 billion Hz). A target radial motion of 50 knots would produce a Doppler frequency shift of 487 Hz which is ***only*** $\sim 2 \times 10^{-5}$ % (.00002 %) of the original transmitted frequency! The WSR-88D's electronics are ***not designed*** to detect such a small amount of frequency change.

(***Note:*** The Doppler frequency shift equations are ***not*** the same for sound and E-M energy. The medium through which waves travel is important for sound but not for E-M energy. This is the reason for the different frequency shifts obtained in the previous examples, even though the target velocity was the same)

WSR-88D velocity detection method

The WSR-88D ***does not*** measure frequency shifts directly to determine target radial velocity but instead uses the ***pulse-to-pulse phase change*** between successive returned pulses which is easily and more accurately measured. This technique is called **"*Pulse-Pair Processing*"**.

For any type of periodic motion, the ***phase*** of a wave is "a point or 'stage' in the period to which the motion has advanced with respect to a given initial point" (Glossary of Meteorology). A complete wave (Figure 11) consists of a 360° cycle (or 2π radians). If a wave was to intercept a target at a position equal to one-fourth its wavelength, it would do so at a phase angle of 90° (or $\pi/2$ radians). For the WSR-88D to be able to extract Doppler motion from targets, the ***initial phase information about each transmitted pulse must be known*** so that the phase of successive returned signals can be compared.

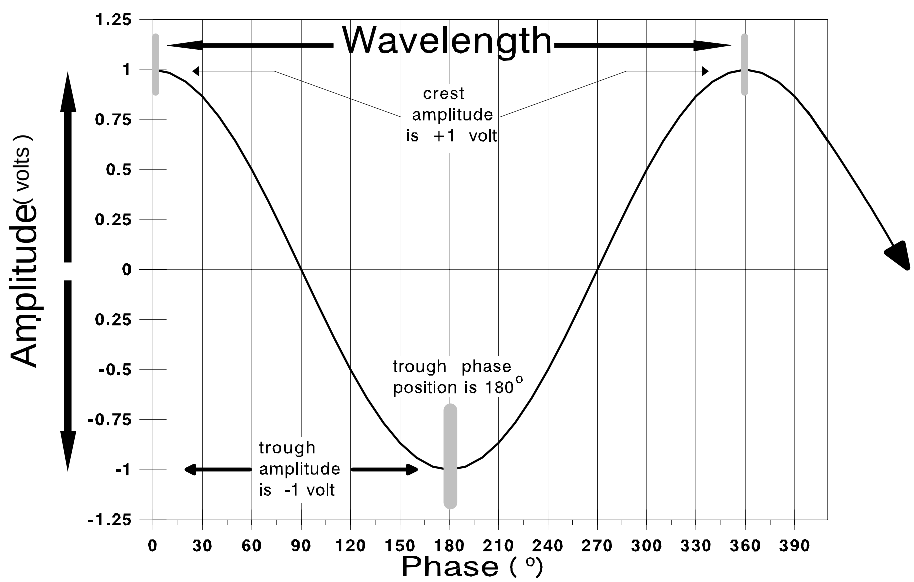


Figure 11. Radar wave characteristics.

Coherency

The WSR-88D is a ***coherent*** radar, which means that phase information for each pulse is known.

The frequency of each transmitted pulse is ***constant*** and the phase is identical to that of an internal reference signal. When the pulse returns, a comparison to this reference signal is used to determine the phase. Any pulse to pulse phase changes can then be computed, which are related directly to target motion.

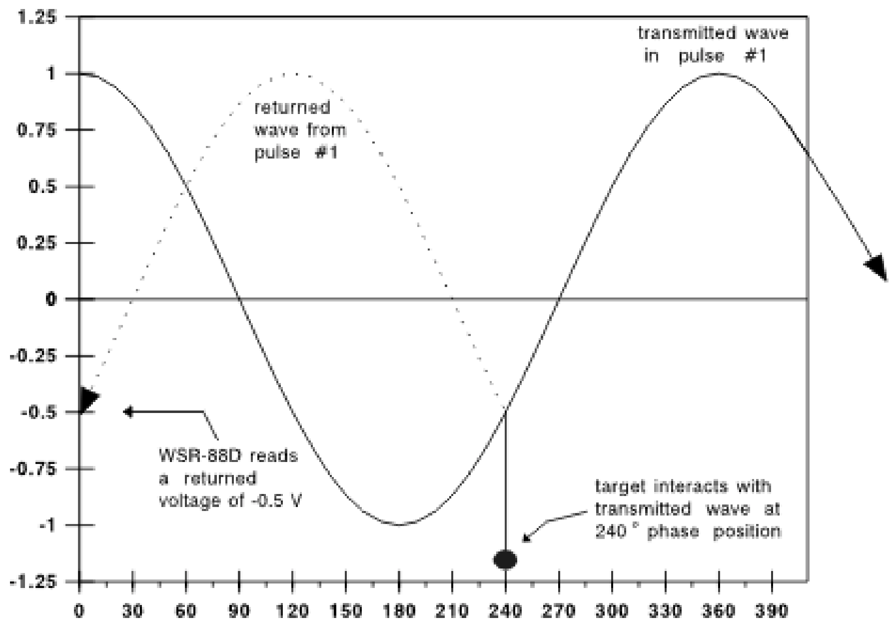


Figure 12. Example of return from the first pulse from an inbound target.

Signal phase and target location

As a target changes ***radial*** position between two successive pulses (Figure 13), the phase of the returned signal will change from pulse to pulse. This occurs because the target intercepts the transmitted wave at a different phase position along the wave. However, if a target moves perpendicular to the radar beam or remains stationary, the phase of the returned signal will not change from pulse to pulse.

Frequency shift vs. phase shift

Recall that Doppler frequency shifts ***also*** occur as a result of a target's radial motion. Pulse-to-pulse phase shifts and Doppler frequency shifts are ***both*** dependent on a target's radial motion. Even though frequency shifts are not ***directly*** mea-

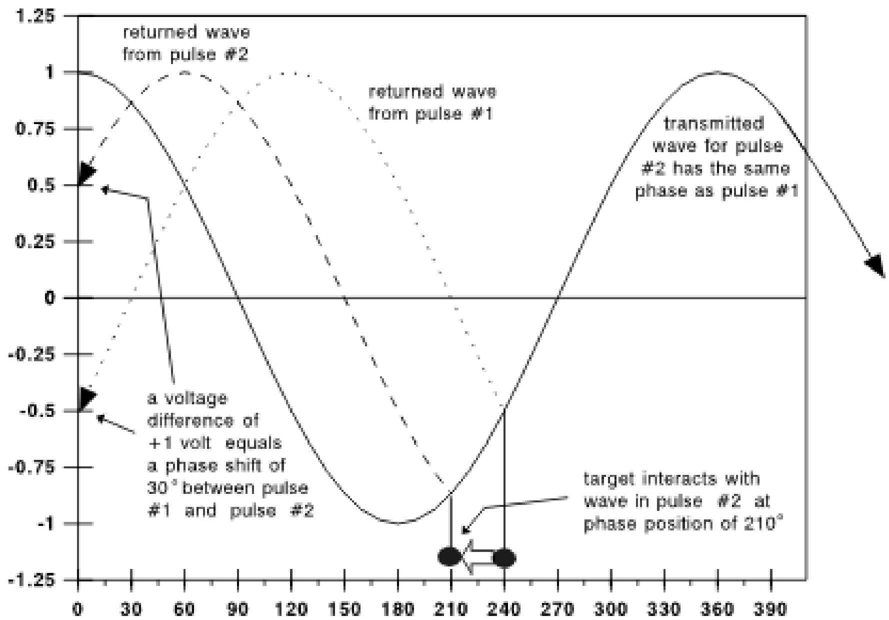


Figure 13. Example of the phase change from an inbound target.

sured, Doppler frequency shifts are inherent within the pulse-to-pulse phase shifts since, by definition, the time rate of phase change equals f_{dop}.

WSR-88D Radial Speed Computation (Objective 3)

The speed the WSR-88D will ***initially*** assign to a range bin is ***directly related*** to the amount of ***phase shift*** between successive returned pulses. However, there is a maximum amount of phase shift, 180°, that the WSR-88D can measure from one pulse to the next. If a target moves too far between pulses such that its true phase shift exceeds 180°, an apparent phase shift of less than 180° would still be assigned.

Pulse pair phase shift and radial velocity

There is a direct relationship between pulse pair phase shift and radial velocity. For any pulse pair phase shift, there is an associated radial velocity.

Since 180° is the maximum phase shift that the WSR-88D can recognize, there is then a maximum velocity that the radar can measure unambiguously. It is the ***maximum unambiguous***

velocity, V_{max}, and it corresponds to a maximum pulse-pair phase shift of 180°.

The process by which the WSR-88D determines target speed is relatively simple once the phase angles of two successive returned pulses have been determined.

1. The phase of the first returned pulse and the phase of the second returned pulse are obtained and the algebraic difference is computed.

2. The pulse-pair phase shift is then compared to the ***maximum measurable*** phase shift of 180° and that amount of phase shift percentage is then multiplied by V_{max}.

This is simply the ratio

$$\frac{\mathbf{P.S.}}{\mathbf{180^\circ}} = \frac{|V_r|}{|V_{max}|} \qquad (4)$$

where **P.S.** is the amount of pulse-pair phase shift, $|V_r|$ is the target speed, and $|V_{max}|$ is the maximum unambiguous speed (magnitude of V_{max}). For any given V_{max}, target speed is directly related to the amount of pulse-pair phase shift that occurs.

Phase shift depiction using phasors

One way to graphically illustrate the concept of pulse-pair phase shift is to use phasors. A ***phasor*** is defined as a rotating vector used to represent an alternating current signal. For use with the WSR-88D, a phasor represents the phase and amplitude (power) of each returned pulse. The phase of each returned pulse is the angle that the phasor sweeps out from the positive x axis. The angle between ***two*** phasors represents the “pulse-pair” phase shift and, hence, the target's speed. Since we are limited to using phase shifts less than 180°, the WSR-88D always uses the ***smaller*** angle between the two phasors to determine the "pulse-pair" phase shift.

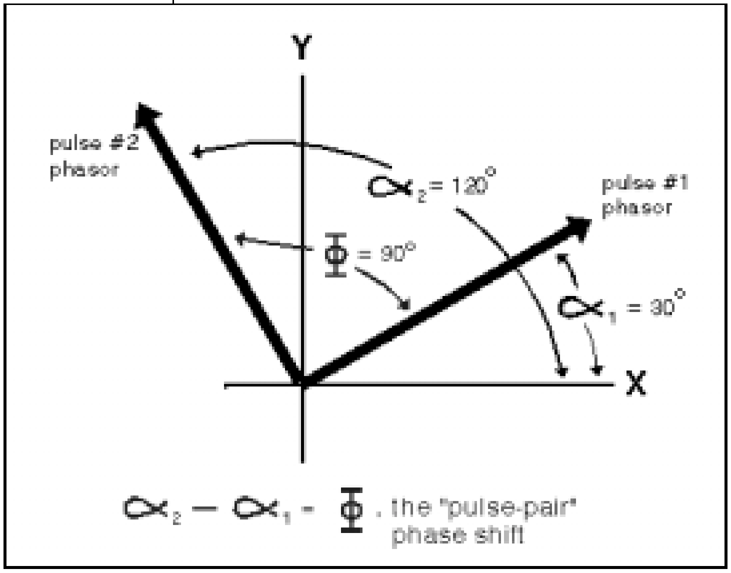


Figure 14. Phasors are used to identify the pulse-pair phase shift.

Example

In Figure 14, the phase for pulse 1, α_1, is 30°, and the phase for pulse 2, α_2, is 120°. The pulse-pair phase shift is then 90°. If V_{max} is 60 knots, then the target's speed will be 30 knots. This answer is obtained by using equation 4, P.S. = 90°, and $|V_{max}|$ = 60 kt such that

$$90°/180° = |V_r| / 60 \text{ kt}$$

$$1/2 = |V_r| / 60 \text{ kt}$$

$$60 \text{ kt } (.5) = |V_r| = 30 \text{ kt}$$

Notice that in this example, we have ***only*** obtained the target's ***speed***, not its direction of motion (inbound or outbound). Also, if V_{max} had been 40 knots instead of 60 knots, the same amount of pulse-pair phase shift would have produced a ***lesser*** target speed of 20 knots. Therefore, there is no unique target speed for every pulse-pair phase shift due to its dependence on V_{max}.

Phase shift and unambiguous velocity

Pulse-pair phase shift less than 180°

If the pulse-pair phase shift is less than 180°, then the target speed and direction can be unambiguously measured and the ***"first guess" velocity*** measurement is ***correct***. See Figure 15.

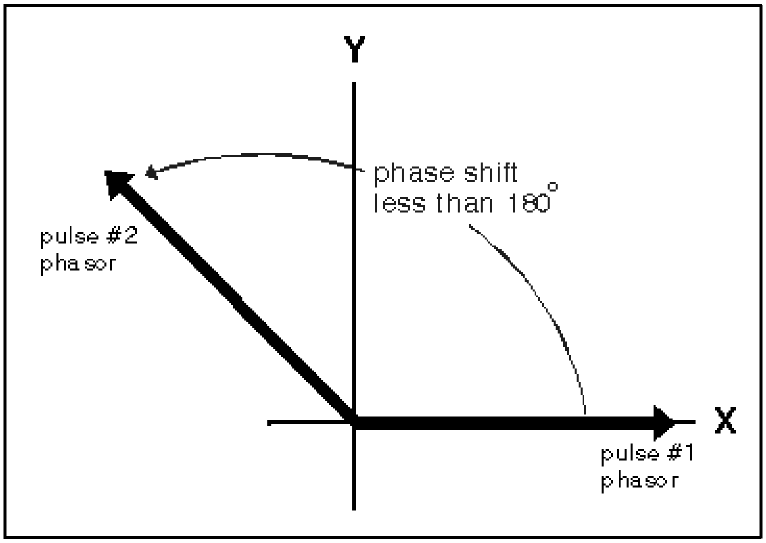


Figure 15. Phase shift of < 180°.

Pulse-pair phase shift equal to 180°

If the pulse-pair phase shift is equal to 180°, then the ***speed*** will be ***correct*** and equal to V_{max}, but the target's ***direction*** (inbound or outbound) will be ***unknown.*** See Figure 16.

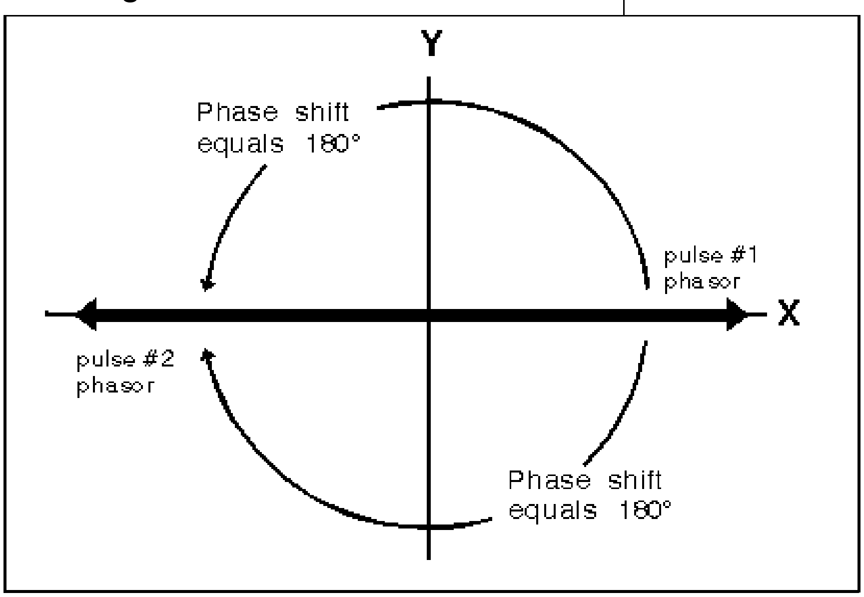


Figure 16. Phase shift of 180°. The speed is correct but the direction unknown.

Phase shift greater than 180°

If the pulse-pair phase shift is greater than 180°, velocity detection is ambiguous. By using the smaller of the two angles between phasors, the radar will assign an improper velocity (both speed and direction) to the target. The ***first guess velocity*** measurement will be **"*aliased*"**. See Figure 17.

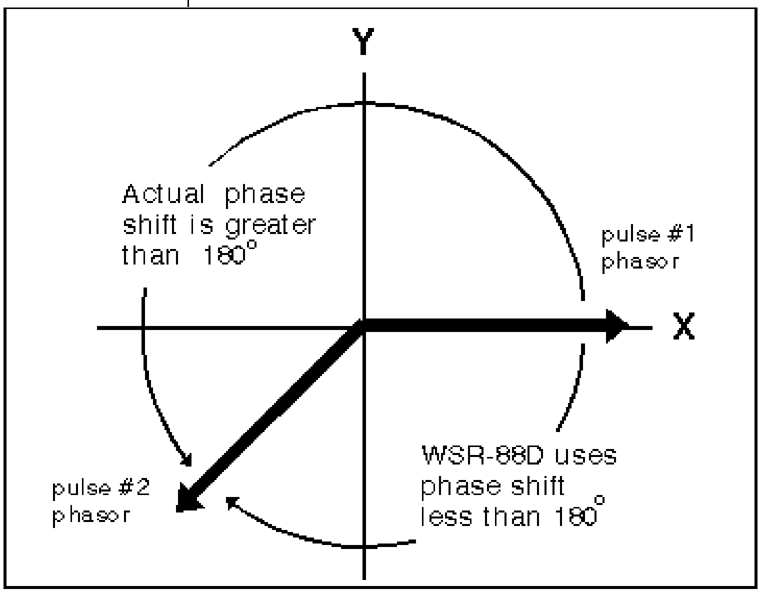


Figure 17. Phase shift of > 180°. First guess speed and direction are incorrect.

If no pulse-pair phase shift is measured, then the target is stationary or, in most cases, moving perpendicular to the radar beam.

When the radial velocity equals or exceeds V_{max}, the radar's first guess velocity will be incorrect or aliased. As a result, the WSR-88D must incorporate a dealiasing algorithm to extract the true radial velocity. To reduce the likelihood of ambiguous or aliased velocities occurring, a target should be sampled frequently so that the target location does not change much between successive pulses. Therefore, the ***best velocity estimates*** are obtained by using ***high PRFs.***

Examples

#1: V_{max} = 60 kts, Phase Shift = 90°

#2: V_{max} = 60 kts, Phase Shift = 45°

#3: V_{max} = 60 kts, Phase Shift = 30°

Obtaining I and Q Values (Objective 4)

Recall that Doppler frequency changes are not measured by the WSR-88D system. Instead, mean radial velocity is determined from the average rate of change of phase between a series of pulse pairs. The amount of pulse-pair phase shift is caused by a change in target range from pulse to pulse.

I and Q components

A target detected by a single pulse will return a signal represented by the phasor in Figure 18. However, since a phasor is a vector, it has both magnitude (amplitude) and direction (phase angle) and has components in the x and y directions. Concerning WSR-88D signal processing, the vector component of a phasor in the x direction is called the In-Phase component (or I component) and the vector component in the y direction is called the Quadrature component (or Q-component).

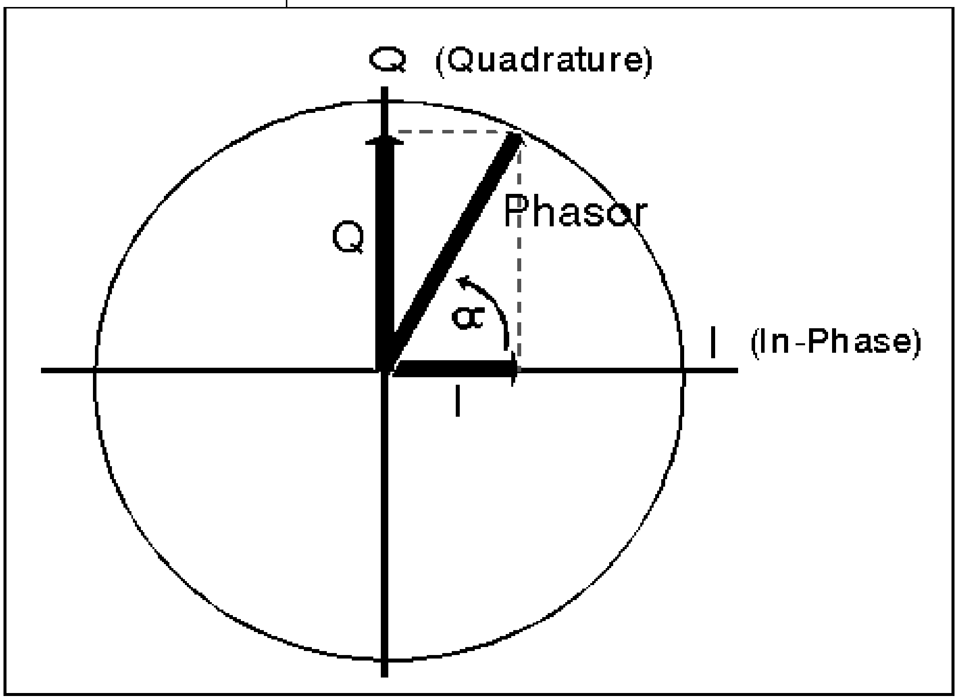


Figure 18. A phasor and its components.

The I and Q components contain all the necessary information to generate the base reflectivity, radial velocity, and spectrum width data. The amplitude of the signal, which is ultimately reflectivity, is computed directly from the I and Q values. Pulse pair phase shifts are also computed directly from the I and Q values, which are then used to generate radial velocity and spectrum width.

The I component (In-Phase) is essentially the returned raw signal. The Q component is the returned raw signal that has been phase shifted +90° (hence, the term Quadrature or 1/4th of 360°) by the internal electronics of the WSR-88D. See Figure 19.

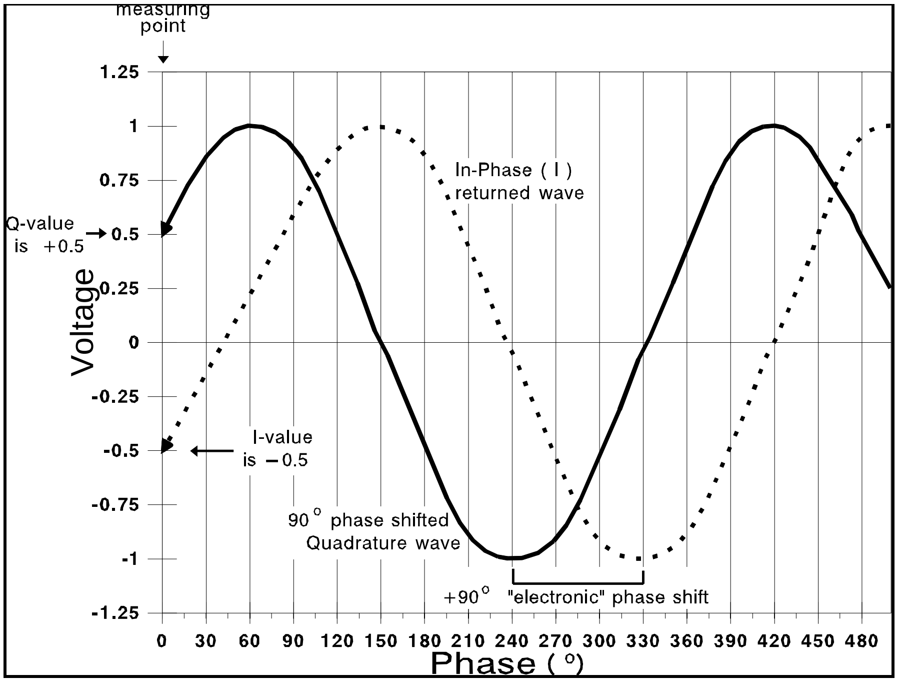


Figure 19. Example of the relationship between I and Q values.

Q value needed for target direction

The I value alone is not sufficient to determine target direction, inbound or outbound. The I and Q values together provide both target speed and direction. This is illustrated in Figure 20 where the I component only is represented. The returned signal from a target at location A is plotted at some initial time, along with the returned signal at some latter time but from two different locations (B and C). Notice that when the target moves to location B, it has the same voltage value as if it had moved to location C. Comparing the voltages from A-B and A-C yields the same phase difference at both locations. From the amount of phase shift computed, we could determine the target's speed, but not its direction or motion. The Q component (not shown here) will provide enough information to determine target motion.

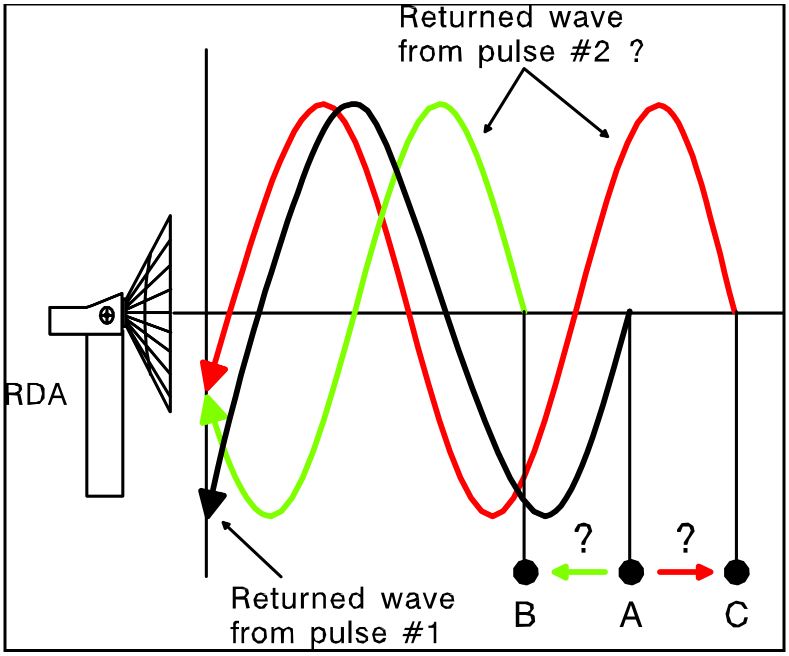


Figure 20. Which way did the target move? Based upon the signal received from the second pulse, the target could have moved from A to B or to C.

Determining target direction

Once the I and Q values for two successive returned pulses have been determined, the respective phasors can be plotted in a Cartesian coordinate system. The ***rotation*** from Phasor #1 to Phasor #2 determines the ***direction*** of the target's radial motion.

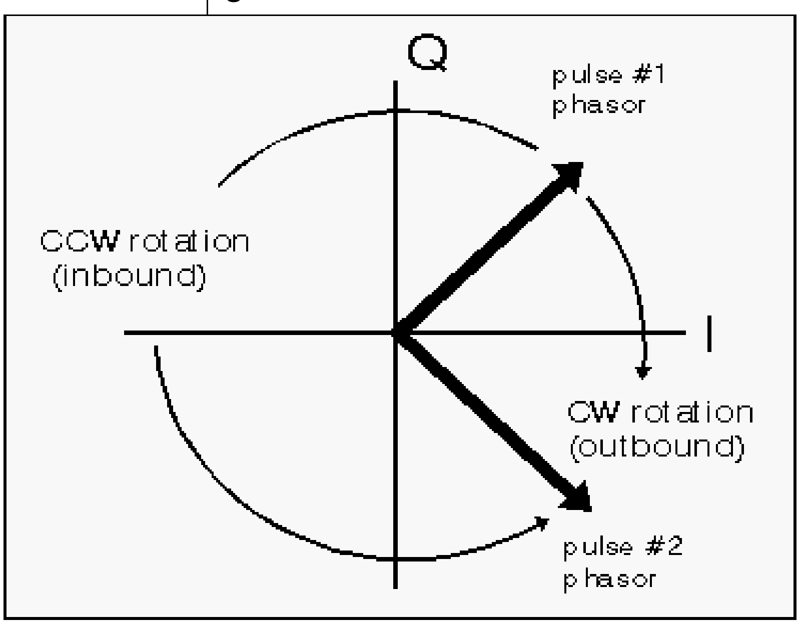


Figure 21. Phasor rotation and target direction.

Figure 21 illustrates the result of the two possible rotations. When trying to find the resultant vector from the cross-product of two vectors, we can use the “right-handed thumb rule” to determine whether target motion is inbound or outbound. Using your right hand, curl your fingers in the direction of rotation from phasor #1 to phasor #2. If your thumb points ***away*** from you, then the apparent target motion is ***outbound*** from the radar. If your thumb points ***toward*** you, then the apparent target motion is ***inbound*** to the radar.

Another way of remembering the relationship between phasor rotation and apparent target motion is:

- ***counterclockwise*** rotation means target motion is ***toward*** the radar and is denoted by a ***negative velocity*** (by convention).
- ***clockwise*** rotation means target motion is ***away*** from the radar and is denoted by a ***positive velocity*** (by convention).

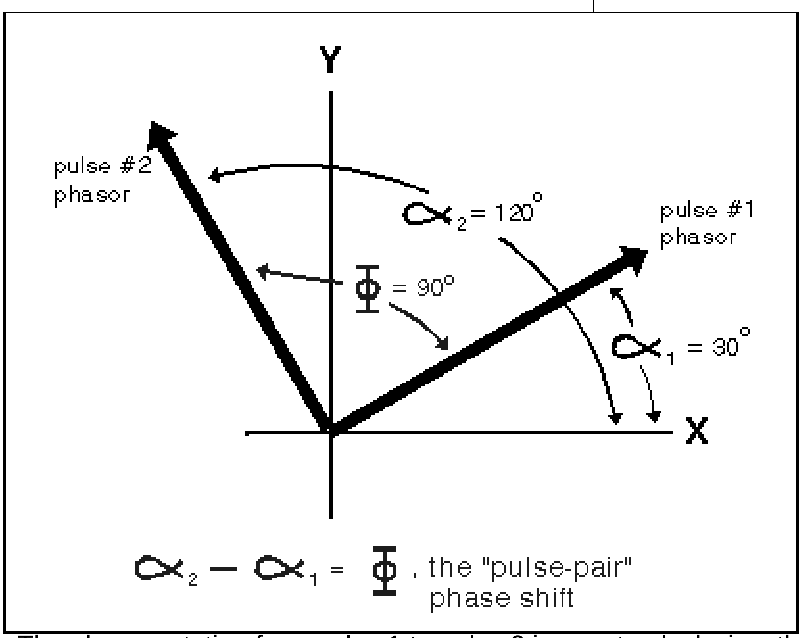


Figure 22. The phasor rotation from pulse 1 to pulse 2 is counterclockwise, thus target motion is toward the radar.

Figure 22 shows the phasors used to demonstrate a pulse pair phase shift. Note that the phase shift from pulse 1 to pulse 2 sweeps out an angle in the counterclockwise direction. Thus the target is moving toward the radar, and the velocity will be denoted by a negative sign.

Note: Objective 4 only requires that you be able to determine target direction and not speed from the plotting of phasors.

Unambiguous velocity calculations using phasors

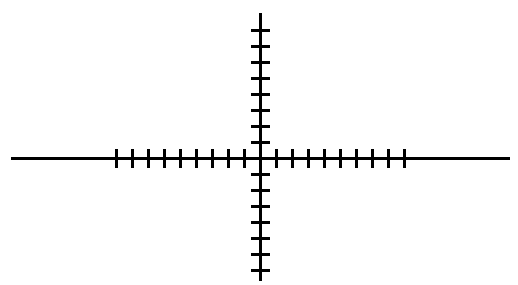
Example #1

Given:

V_{max} = 60 KT (180° Phase Shift)

Phasor #1: $I_1 = +4$ AND $Q_1 = +4$

Phasor #2: $I_2 = -4$ AND $Q_2 = 0$



The pulse-pair phase shift from #1 to #2 is _____° and phasor rotation is (clockwise/counterclockwise) indicating that the apparent target motion is (toward/away from) the radar at _____ knots. The first guess velocity would be _____.

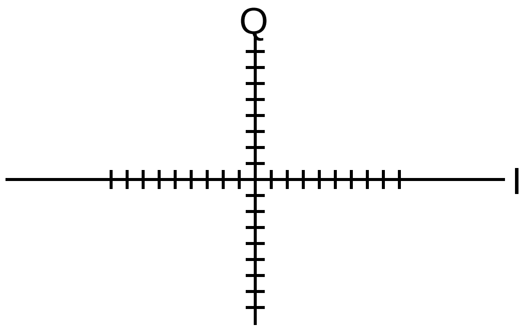
Example #2

Given:

V_{max} = 60 KT (180° Phase Shift)

Phasor #1: $I_1 = +4$ AND $Q_1 = -4$

Phasor #2: I_2 = -4 AND Q_2 = 0



The pulse-pair phase shift from #1 to #2 is _____ ^{o} and phasor rotation is (clockwise/counterclockwise) indicating that the apparent target motion is (toward/away from) the radar at _____ knots. The first guess velocity would be ______.

When the actual phase shift exceeds 180°

Recall that the WSR-88D always assumes the phase shift due to target motion is the smaller angle between phasors #1 and #2. What happens when the ***actual*** phase shift is greater than 180°? The apparent, or first guess, target motion will be ambiguous. The radial speed will be less than what it actually is and the target direction will be opposite the true direction.

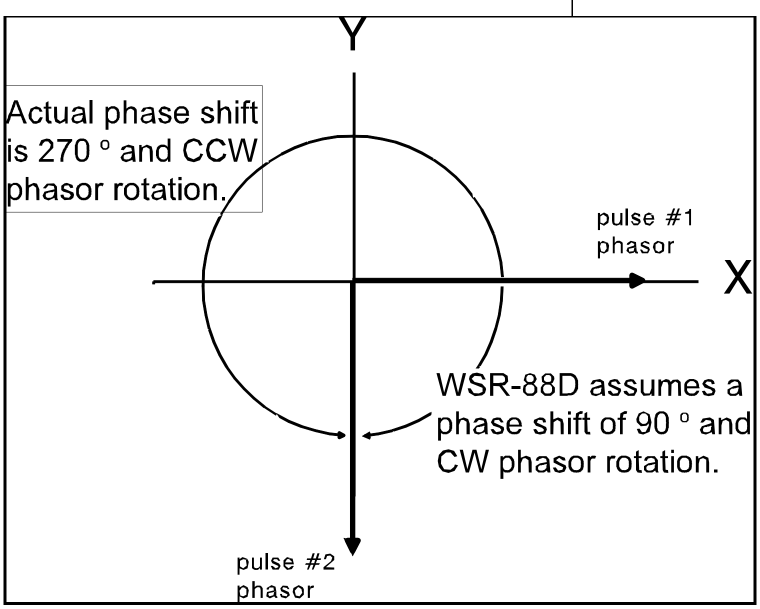


Figure 23. When the actual phase shift exceeds 180°, the WSR-88D will still use an angle smaller than 180° to compute a first guess velocity.

Ambiguous velocity calculations using phasors

Example #3:

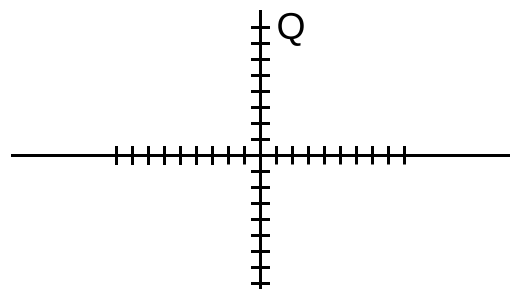
Given:

V_{max} = 60 KT (180° Phase Shift)

Phasor #1: I_1 = +4 AND Q_1 = 0

Phasor #2: I_2 = 0 AND Q_2 = -4

Actual pulse-pair phase shift is 270° and phasor rotation is CCW



The ***actual*** target motion is (toward/away from) the radar at ____ knots. However, the WSR-88D's first guess at target motion will assume a phase shift of ______**°** and phasor rotation that is (clockwise/counterclockwise) indicating that the apparent target motion is (toward/away from) the radar at ______ knots.

Key points to remember about velocity calculations

- The WSR-88D ***always*** assumes phase shifts are < 180° and ***always*** chooses the angle < 180°.
- Actual phase shifts ≥ 180° will result in velocities that are ***incorrect*** or ***ambiguous*** and are referred to as being aliased velocities.

Signal Processing Review Exercises

1. The WSR-88D is a "coherent" system. What does this mean?

2. The Doppler Effect is defined as the change in frequency with which energy reaches a receiver when the receiver and energy source are in motion relative to each other.

a. Does the WSR-88D directly measure a frequency shift? Why or why not?

b. What other characteristic of wave energy changes due to target motion? Can the WSR-88D measure this?

3. A target is moving due south at 40 knots. It is situated 20 nm to the west-southwest of the RDA (240°/20 nm). What velocity will the radar detect?

4. For a given range bin, compute the *speed* the WSR-88D will *initially* assign if:

a. V_{max} = 40 knots, pulse pair phase shift is 45°.

b. V_{max} = 60 knots, pulse pair phase shift is 135°.

c. V_{max} = 60 knots, pulse pair phase shift is 225°.

5. Select the degree of phase shift such that a smaller shift is unambiguous and an equal or greater shift is ambiguous.

a. 90°
b. 180°
c. 270°
d. 360°

6. If V_{max} = 40 knots, identify a set of possible radial velocities (knots) if the pulse pair phase shift is 90° counter-clockwise. Hint: Use a technique similar to the one you used in 4c above.

a. -20, -100, +60, +140
b. -20, -60, +20, +60
c. -10, -50, +30, +70
d. -10, -90, +70, +150

7. If I = 3 and Q = 3, graphically generate a phasor and identify its amplitude and phase (relative to the positive x axis.)

8. In a range bin, assume I = 3 and Q = 3 from the first pulse, while I = 0 and Q = 5 from the second pulse. If the radar's first guess is correct, is the mean target motion toward or away from the radar?

Base Data Generation

Generating base data of the highest quality is of paramount importance. Once generated, the base data are sent, via the wideband, to the RPG. At the RPG, the base data are input to ***all*** the algorithms, building ***all*** the Base and Derived products. This section completes the necessary foundation for studying the WSR-88D data quality issues.

Objectives

Without references, and in accordance with the lesson, you will

1. Identify how the returned signal is used to generate the Base Reflectivity, Velocity, and Spectrum Width Data.

2. Given four examples, identify which will have the greatest spectrum width.

3. Identify how non-meteorological factors affect the magnitude of spectrum width.

Base Data Estimation Considerations (Objective 1)

Single pulse estimates have a statistical uncertainty that is too large to yield accurate base data. Therefore, a large number of pulses must be processed to provide required accuracy. The actual number of pulses required depends on the radar system characteristics (e.g. VCP and elevation slice).

Base reflectivity data

The amount of returned power (P_r) from a range bin can be measured and by using the radar equation, Z can be indirectly determined. Mean returned power information is generated for ***each*** .13 nm (1° X 1/4 km) range bin. The number of pulses (6 to 64) used in the computation varies depending on VCP and elevation slice and typically produces an error $\leq$ 1 dB.

Four steps to dBZ estimates

Step 1. The average power for each .13 nm range bin is obtained.

Step 2. The average power returned (P_r) from ***4 successive*** .13 nm (250 m) ***range bins*** is obtained; since 4 range bins are used, the ***best*** available ***range resolution*** for reflectivity is .54 nm; the average power equation is

$$\overline{P_{\mathrm{r}(.54)}} = \frac{(\overline{P_{r1}} + \overline{P_{r2}} + \overline{P_{r3}} + \overline{P_{r4}})}{4} \qquad (5)$$

Step 3. From the radar equation ($Z = P_r R^2/C$), reflectivity (Z) is obtained.

Step 4. Z is then converted to dBZ by using the equation; dBZ = 10 log Z.

The best reflectivity data is obtained using a low PRF since this ***increases*** listening time between pulses and ***increases*** R_{max} which helps to eliminate the possibility of second trip echoes. For ***all VCPs***, the lowest 2 slices each have 2 full antenna rotations employing first the CS and second the CD mode.

Base mean radial velocity data

Doppler velocity information is obtained by a technique called pulse-pair processing which is employed to determine the phase shift, if any, between successive returned pulses for a ***given range bin***. Velocity information is obtained via a three step process:

Step 1. 40-50 pulse-pairs are required to generate a statistical error of $\leq$ 2 KT for each .13 nm range bin.

Pulse-pair phasors summed vectorially

Step 2. This step uses ***pulse-pair phasors,*** which simply represent the information for each pulse pair. The angle from the positive x axis is the pulse pair phase shift, while the amplitude is the product of the phasors of each individual pulse. The pulse-pair phasors are summed vectorially. See Figure 24.

Velocity Estimate is Power Weighted

The phasors with larger magnitudes (higher returned power) have a ***greater*** impact on the mean radial velocity estimate. Thus velocity estimates are ***power weighted,*** meaning that the larger scatterers returning higher power have the greater weight in the velocity average. The larger targets tend to move with the mean flow, thus the velocity estimate is not contaminated by smaller targets which tend to move with microscale flows.

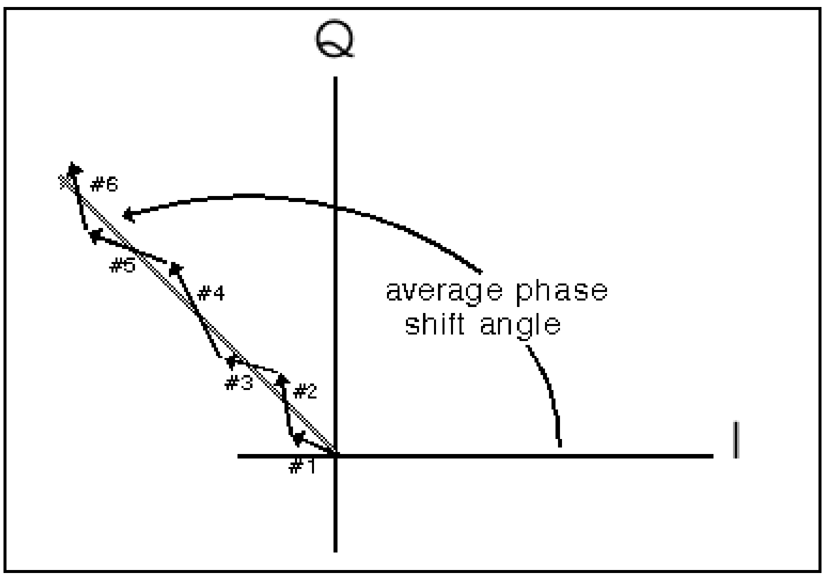


Figure 24. The average phase shift is obtained by vectorially adding all of the pulse-pair phasors.

Step 3. Mean radial velocity base data is assigned to ***each*** .13 nm range bin out to a range of 124 nm.

Base spectrum width data

Spectrum Width data is a measure of the amount of ***velocity dispersion*** within the range bin. Spectrum Width is mathematically proportional to the variation of speed and direction within a range bin. Spectrum Width data can be used as a “Velocity Quality Control” tool since the reliability of velocity estimates decrease as Spectrum Width estimates increase.

Meteorological conditions

Some meteorological features or conditions typically associated with relatively high spectrum widths include:

- Boundaries such as fronts, outflow boundaries, etc.
- Thunderstorms
- Shear regions
- Turbulence
- Wind Shear

Statistical autocorrelation

Spectrum width estimates are obtained using a statistical technique called Autocorrelation which is simply a measurement of the variability of the signal from successive returned pulses. This method assumes that the Doppler power spectrum (Figure 25) is Gaussian (normal distribution about a mean value). Since spectrum width is obtained from the velocity data, the ranges displayed for spectrum width are identical to base velocity.

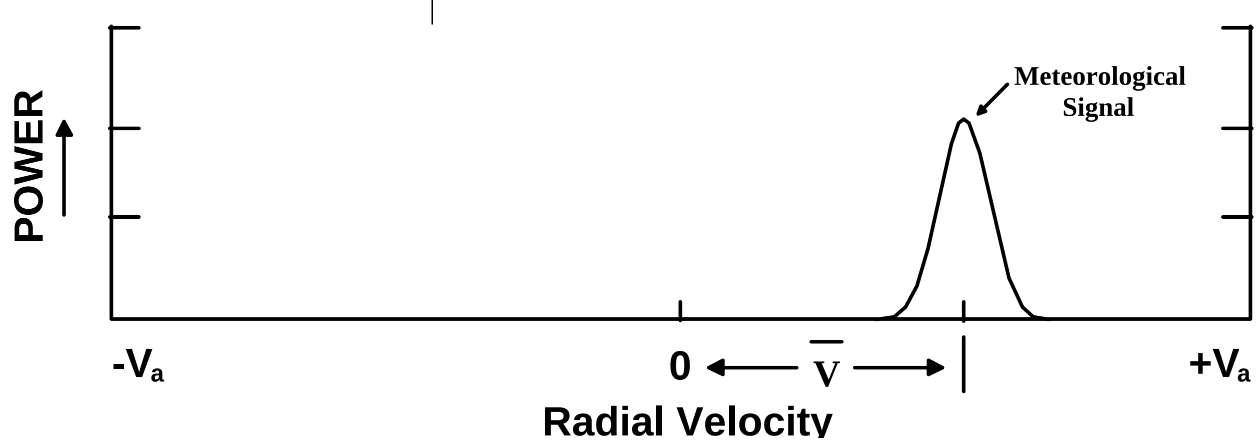


Figure 25. A Doppler Power Spectrum: Gaussian distribution of power returned from a meteorological target.

Low vs High Spectrum Width

The magnitude of spectrum width can vary significantly. Since velocity estimates are power weighted, the power distribution greatly influences the resultant spectrum width.

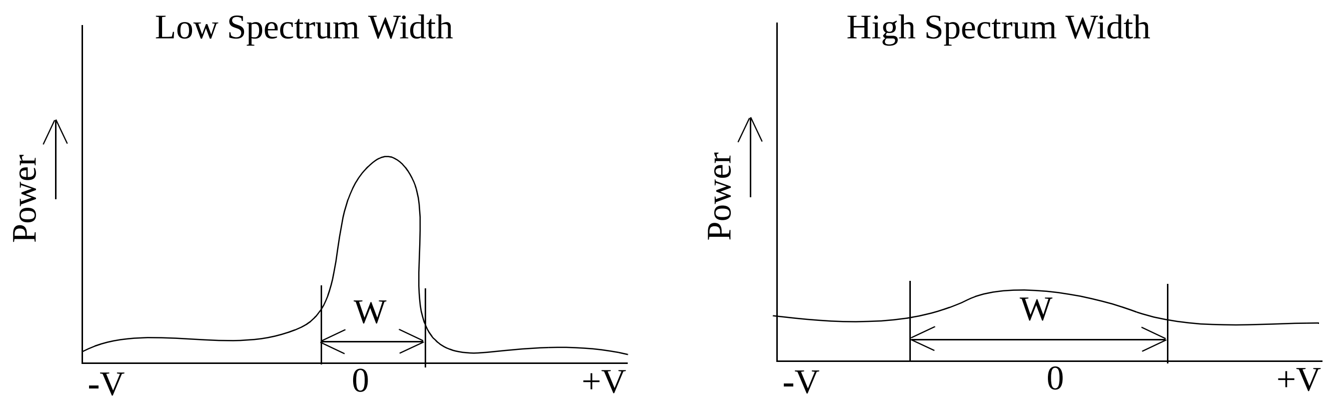
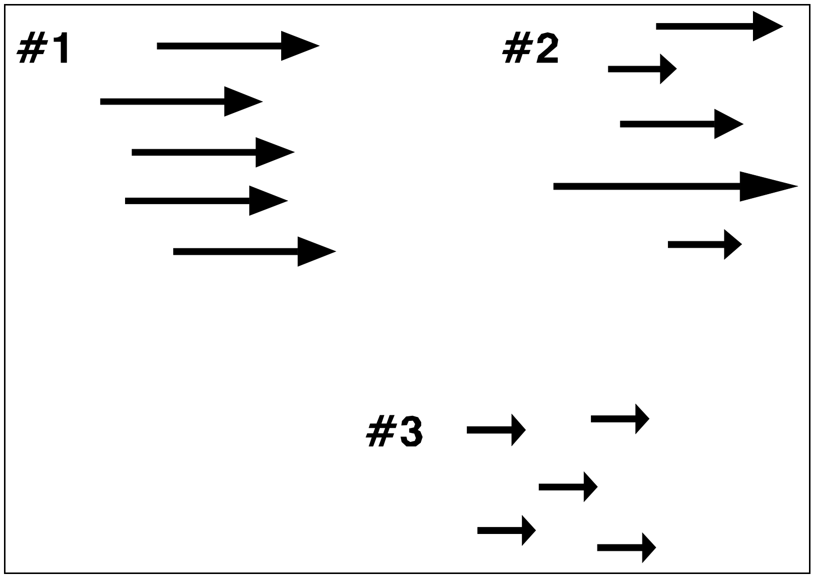


Figure 26. The high power signal on the left diagram generates a low spectrum width. On the right diagram, the spectrum width is higher without the high power signal.

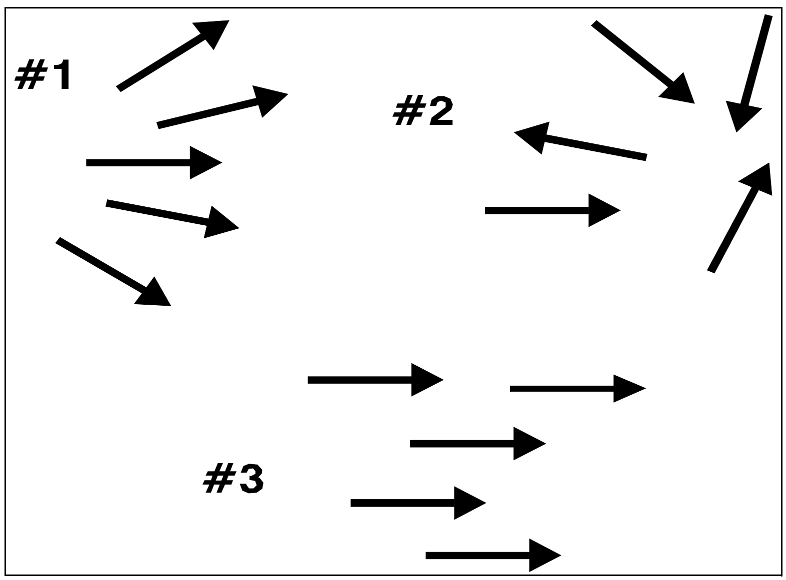
Spectrum Width - Meteorological Factors (Objective 2)

Examples

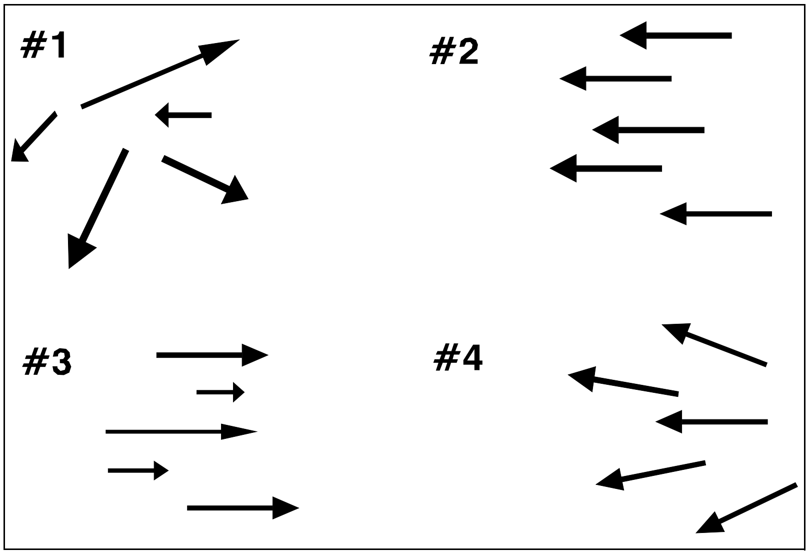
In the following examples, identify which group of scatterers has the ***highest*** spectrum width value. The length of the arrow represents the speed and the direction of the arrow represents the direction of motion of the scatterer in the range bin.



Example 1



Example 2



Example 3

Spectrum Width - Nonmeteorological Factors (Objective 3)

There are other factors not related to meteorology that will have an impact on the spectrum width values displayed on the products.

Range

The range bin size is directly related to target range. As range increases, range bin size increases, as does the likelihood of differences in velocities within the range bin. Therefore, the spectrum width will increase as well.

For example, at 120 nm the radar beam is 2 nm wide. Within this large volume, there is a very good chance of significant differences in the motion of targets. As the antenna sweeps, collecting data for a range bin, these differences in velocity within each sample volume will contribute to a higher spectrum width assigned to the range bin.

Signal-to-Noise ratio (SNR)

Typically signals from very weak returns close to the noise level have higher spectrum widths. This is because system noise is low in power but spread across the entire velocity spectrum, resulting in a high spectrum width value. When the returned signal is close to the noise level within the system, the signal processor has difficulty separating the weak signal from the noise and displays it as high spectrum width.

Ground clutter and anomalous propagation

Spectrum width data values from ground clutter/AP are target dependent. For example, high spectrum widths can result when the radar detects the motion of the vehicles along a highway. If the range bin contains buildings ***and*** eddies around the edges of the buildings, spectrum widths will be higher, while low spectrum width values are calculated if only the building is filling the beam.

Base Data Generation Review Exercises

1. How is dBZ obtained from mean power estimates for each .54 nm resolution range gate?

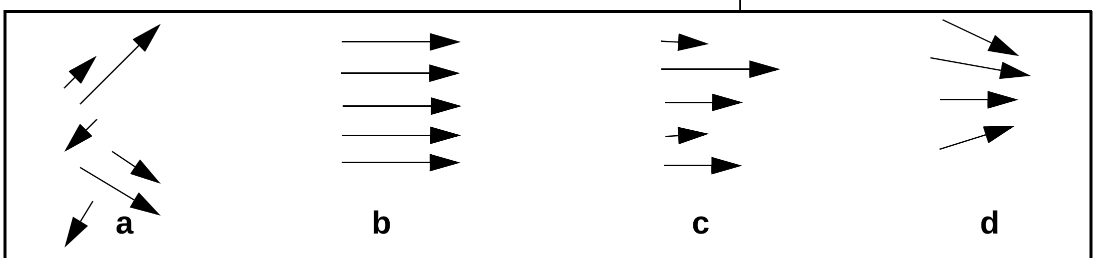
2. The technique employed by the WSR-88D to estimate mean radial velocity is

a. spectral processing (DFT.. discrete Fourtier transform technique.)
b. pulse-pair processing
c. a combination of spectral and pulse-pair processing that minimizes estimate error
d. the finite-element method

3. How does the WSR-88D estimate spectrum width?

a. The maximum difference between detected velocities from targets in a range bin is determined, then this value is divided by 2.
b. Statistical autocorrelation, which measures the variability of the signal over successive pulses.
c. Spectral processing generates information concerning the degree of dispersion from the Discrete Fourier Transform.

4. Which of the following four range bins will possess the greatest spectrum width?



5. List the three non-meteorological factors and their effect on the magnitude of spectrum width.

Mitigation of Data Ambiguities

There are inherent limitations in pulsed Doppler radars, of which the operator must have a working knowledge in order to make appropriate interpretations of the radar products. For example, this section will provide the basis for distinguishing between accurate vs. false reflectivity and velocity signatures. Other data quality problems can mask significant features. This section examines data quality issues with the WSR-88D, and includes mitigation techniques that ensure the best possible base data for product generation.

A note on terminology

Though often used interchangeably, range gate and range bin have different meanings. Here, range gate will be used when describing the appearance on WSR-88D products, and range bin will be used when describing algorithm functions.

Objectives

Without references, and in accordance with the lesson, you will

1. Identify the impact that PRF changes will have on R_{max} and V_{max}; i.e. the “Doppler Dilemma.”

2. Given WSR-88D Base Products, identify areas of:

Ground Clutter Contamination
Anomalous Propagation
Range Folding
Improperly Dealiased Velocities

3. Identify strengths and limitations of the following algorithms:

Ground Clutter Suppression
Range Unfolding
Velocity Dealiasing

4. Identify ways the RPG HCI operator can minimize:

Velocity Aliasing
Range Folding

PRF effects on R_{max} and V_{max} (Objective 1)

R_{max} Definition

Maximum unambiguous range is the longest range to which a transmitted pulse can travel and return to the radar before the next pulse is transmitted.

$$R_{max} = \frac{c}{2 \cdot PRF}$$

R_{max} = maximum unambiguous range
c = speed of light
PRF = pulse repetition frequency

V_{max} Definition

Maximum unambiguous velocity is the maximum mean radial velocity that the radar can measure unambiguously. V_{max} corresponds to a pulse pair phase shift of 180º which is the largest pulse pair phase shift that the WSR-88D can measure without ambiguity.

$$V_{max} = \frac{\lambda \cdot PRF}{4}$$

V_{max} = maximum unambiguous velocity
λ = wavelength (WSR-88D ≈ 10 cm)
PRF = pulse repetition frequency.

Key Points

V_{max} and R_{max} depend on PRF

In equations for both V_{max} and R_{max}, PRF is the only variable on the right hand side.

R_{max}

Inverse dependence: As PRF increases, R_{max} decreases, and as PRF decreases, R_{max} increases.

V_{max}

Direct dependence: As PRF increases, V_{max} increases, and as PRF decreases, V_{max} decreases.

“Doppler Dilemma”

Since there is no single PRF that maximizes ***both*** R_{max} and V_{max}, a variety of PRFs are used. Each WSR-88D site uses different PRFs from a set of eight. A typical example is:

PRF #	PRF	Rmax (nm)	Vmax (kt)
1	322	252	16
2	446	181	22
3	644	126	32
4	857	95	43
5	1014	80	51
6	1095	74	55
7	1181	69	59
8	1282	63	64

Figure 27. A sample listing of PRFs available for a particular WSR-88D. Each site will employ one of five sets of PRFs.

Each WSR-88D site has a set of 8 different PRFs, one of which is used depending on the VCP, elevation slice, and waveform.

VCPs 11, 21, and 32

For VCPs 11 and 21, PRFs 1, 2, and 3 are used for Contiguous Surveillance mode (CS), while VCP 32 uses PRFs 1 and 2 (Figure 28). Note from Figure 27 that the R_{max} values that are associated with PRFs 1, 2, and 3 are quite acceptable, while the V_{max} values would produce significant aliasing for most meteorological conditions. Thus, for accurate velocity estimates, PRFs 4, 5, 6, 7, and 8 are used for Doppler mode (CD). Note from Figure 27 the high V_{max} values associated with these PRFs,

VCP	Mode	PRFs	Manually Select?
11	CS	1, 2, 3	No
	CD	4, 5, 6, 7, 8	Yes
21	CS	1, 2, 3	No
	CD	4, 5, 6, 7, 8	Yes
31	CS	1	No
	CD	2	No
32	CS	1, 2	No
	CD	4, 5, 6, 7, 8	Yes

Figure 28. Table of PRFs used for Surveillance and Doppler mode in each VCP. Note that the Doppler PRFs are manually selectable in VCPs 11, 21, and 32.

while R_{max} is much shorter. Note that the five Doppler PRFs can be manually changed (Figure 28).

VCP 31

For VCP 31, PRF 1 is used for Surveillance mode, while PRF 2 is used for Doppler mode (Figure 28). Thus the range information will be accurate, but velocity aliasing will be more significant in VCP 31 than the other VCPs.

Data Recognition and Algorithms (Objectives 2 & 3)

This section will present examples of data ambiguities and contamination that are inherent in meteorological Doppler radar. The algorithms that are designed to mitigate data ambiguities and remove contamination will be presented in the order that they are executed. At the RDA, Ground Clutter Suppression is performed on the digital data as it leaves the signal processor. The Range Unfolding Algorithm is next performed, and the reflectivity, velocity, and spectrum width base data are transmitted via the wideband to the RPG. Velocity

Dealiasing is performed as the first task at the RPG.

Ground Clutter Contamination

Ground clutter contamination occurs when the returned signal from stationary or nearly stationary, non-meteorological targets is processed into the base data. Ground clutter contamination has a significant effect on the accuracy of the base data. Since ***all*** products and algorithms are built from the base data, ground clutter contamination will affect both Base and Derived Products. A particularly sensitive example is precipitation estimation.

General Characteristics

Lowest elevation slices

Ground clutter contamination is most prevalent on the lowest elevation angle products.

Close range

Ground clutter contamination typically occurs at ranges close to the radar.

Occurs during most atmospheric conditions

For any particular elevation angle, ground clutter contamination typically exhibits little change from one volume scan to the next, and will be present most of the time.

Reflectivity Products

Highly reflective targets

Ground targets will typically return high power values close to the radar, with the WSR-88D assigning high reflectivity values if the ground returns are not suppressed. The reflectivity values will appear somewhat randomly distributed, with significant changes from one range gate to the next (Figure 29).

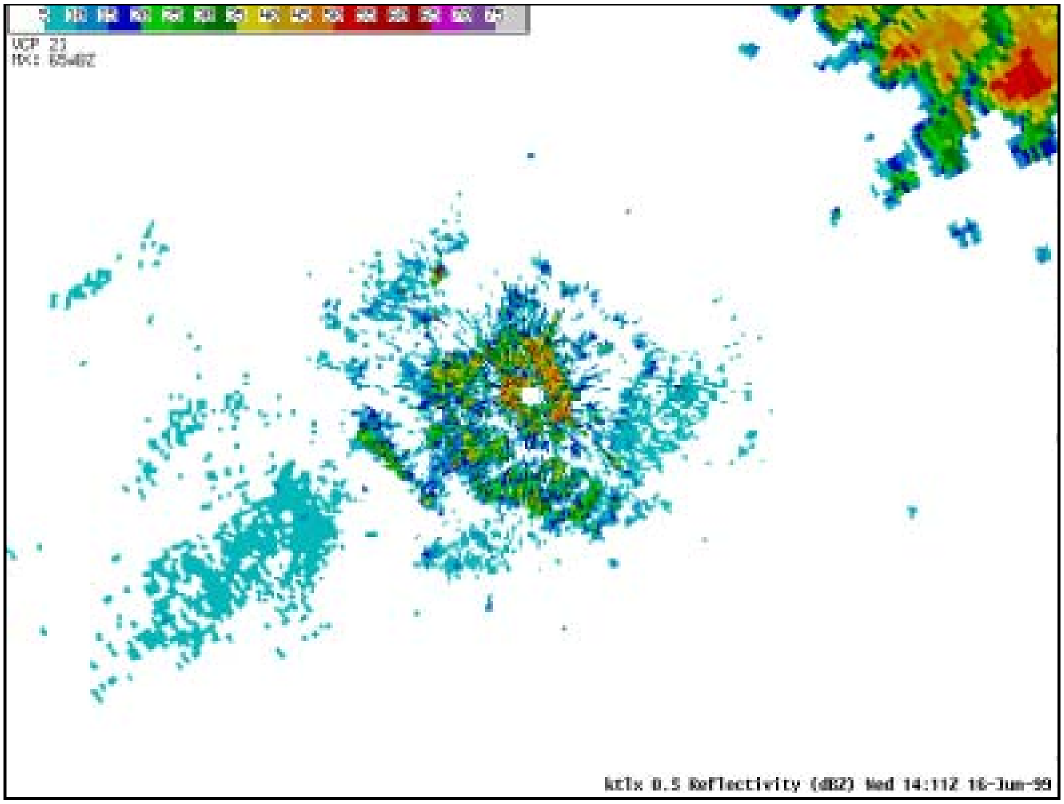


Figure 29. Example of ground clutter contamination on a Base Reflectivity product.

Mean Radial Velocity Products

Typically low to zero velocities

Since ground targets are stationary, radial velocity values are typically near zero. There will, however, be exceptions. Nonzero returns can occur from leaves fluttering in trees, waves on the ocean, cars, etc. Larger structures, such as buildings or water towers, can provide varying velocity values depending on the size of the structure relative to the range bin size, and the speed of the flow around the structure. Since velocity estimates are power weighted, the high power from stationary ground targets typically dominates and the velocity estimate is near zero. Ground clutter contamination on a Mean Radial Velocity product is characterized by a general field of near zero velocities with embedded, isolated nonzero values.

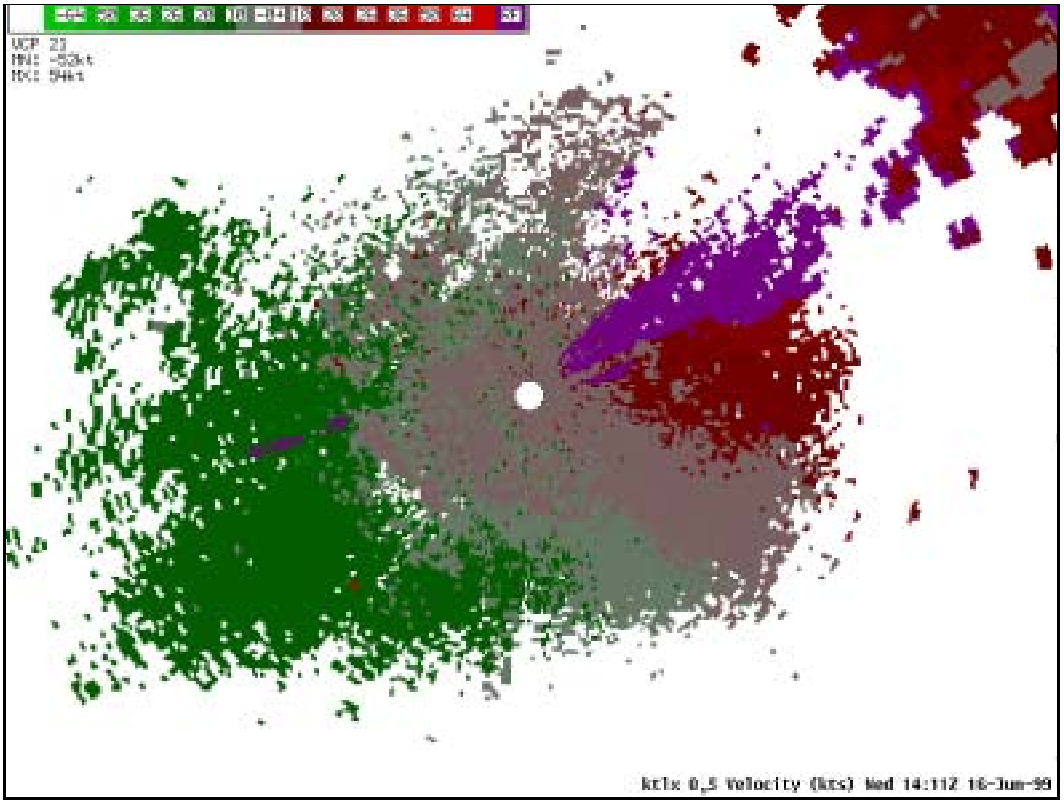


Figure 30. Example of ground clutter contamination on the Base Velocity product corresponding to Fig. 29.

Spectrum Width Products

Typically low spectrum widths

Velocity dispersion from ground targets is generally low, thus spectrum widths tend to be low. As with Mean Radial Velocity products, there are exceptions. Higher spectrum width values may result from leaves fluttering in trees, waves on the ocean, cars, etc. Larger structures can provide varying spectrum width values depending on the size of the structure relative to the range bin size, and the speed of the flow around the structure. Ground clutter contamination on a Spectrum Width product is characterized by a general field of low spectrum widths with embedded higher values.

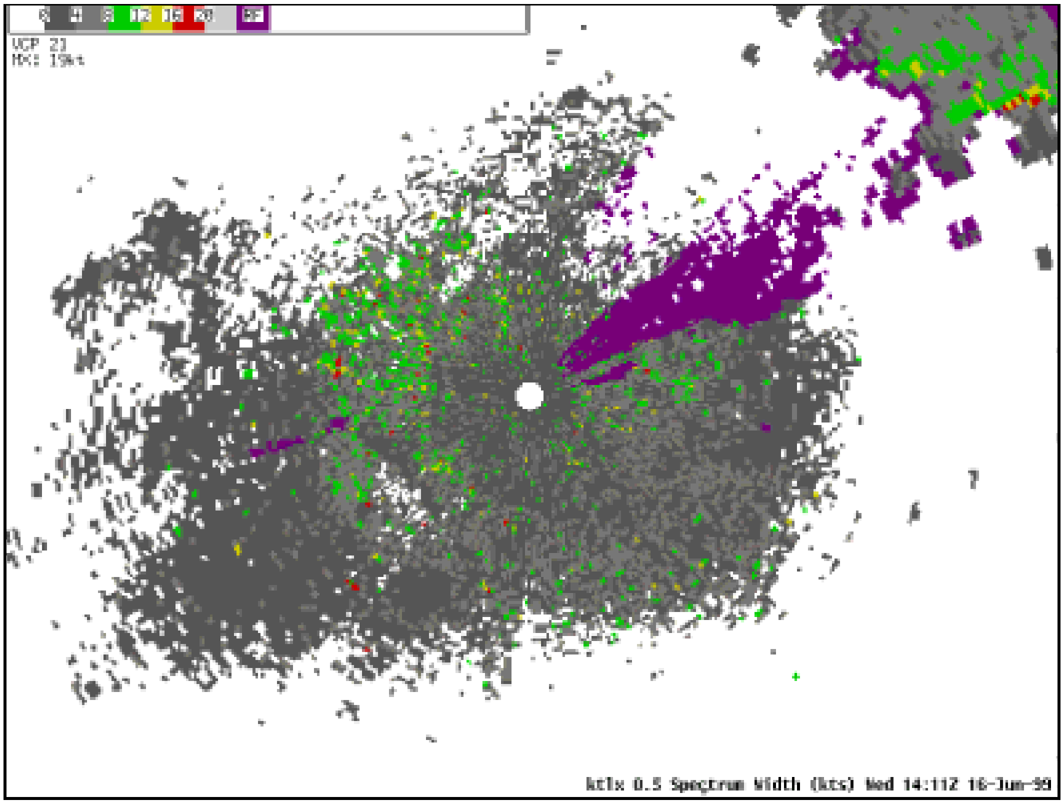


Figure 31. Example of ground clutter contamination on the Base Spectrum Width product corresponding to Fig. 29.

Anomalous Propagation

Anomalous propagation is dependent on atmospheric conditions and is thus transient. This type of ground return displayed on WSR-88D products will typically change from day to day, hour to hour, or even volume scan to volume scan.

In the upcoming discussion on Clutter Suppression, it will be important to distinguish between normal vs. transient ground clutter.

General Characteristics

Lowest elevation slices

Anomalous propagation returns will be most prevalent on the lowest elevation angle products.

Varying ranges

Anomalous propagation returns will occur at varying ranges from the radar.

Superrefractive atmospheric conditions

Superrefractive conditions can be expected in a layer where the temperature increases with height and/or moisture decreases with height.

Reflectivity Products

Mottled appearance

Reflectivity data will have a mottled appearance, with widely varying values typically extending over a large area.

Lacking smooth reflectivity gradients

The high resolution reflectivity data with the WSR-88D makes the nonuniform appearance of ground returns generally quite apparent. Reflectivity values will often be quite high, with abrupt transitions from low to high values. The reflectivity gradients will ***not*** have the smoothness of meteorological returns.

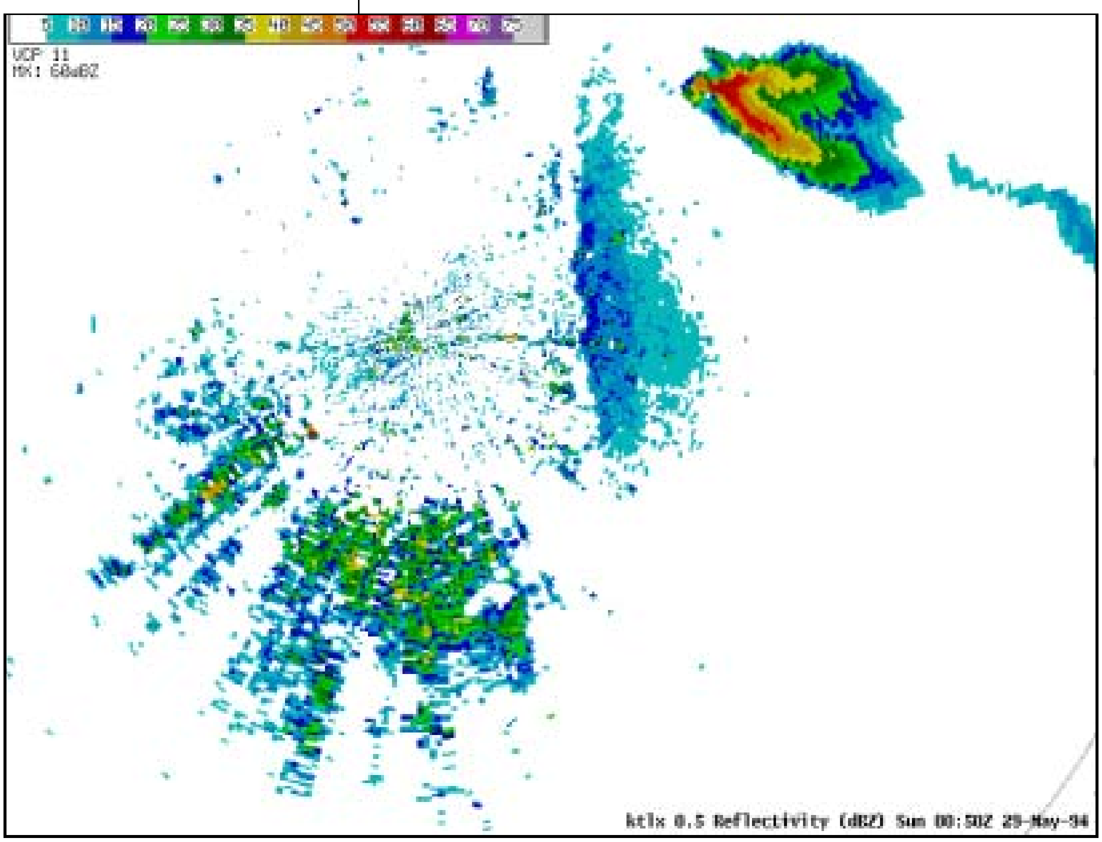


Figure 32. Example of anomalous propagation on a Base Reflectivity product. Note the mottled appearance and high values in the returns to the southwest of the RDA, as compared to the meteorological returns to the northeast of the RDA.

Mean Radial Velocity Products

Typically low to zero velocities

As with normal ground clutter contamination, returns under superrefractive conditions are from ground targets, which are generally stationary. Thus, velocity values are typically near zero, with some exceptions. Nonzero returns can occur from leaves fluttering in trees, waves on the ocean, cars, etc. Larger structures, such as buildings or water towers, can provide varying velocity values depending on the size of the structure relative to the range bin size and the speed of the flow around the structure. Anomalous Propagation on a Mean Radial Velocity product is characterized by a general field of near zero velocities with embedded, isolated nonzero values.

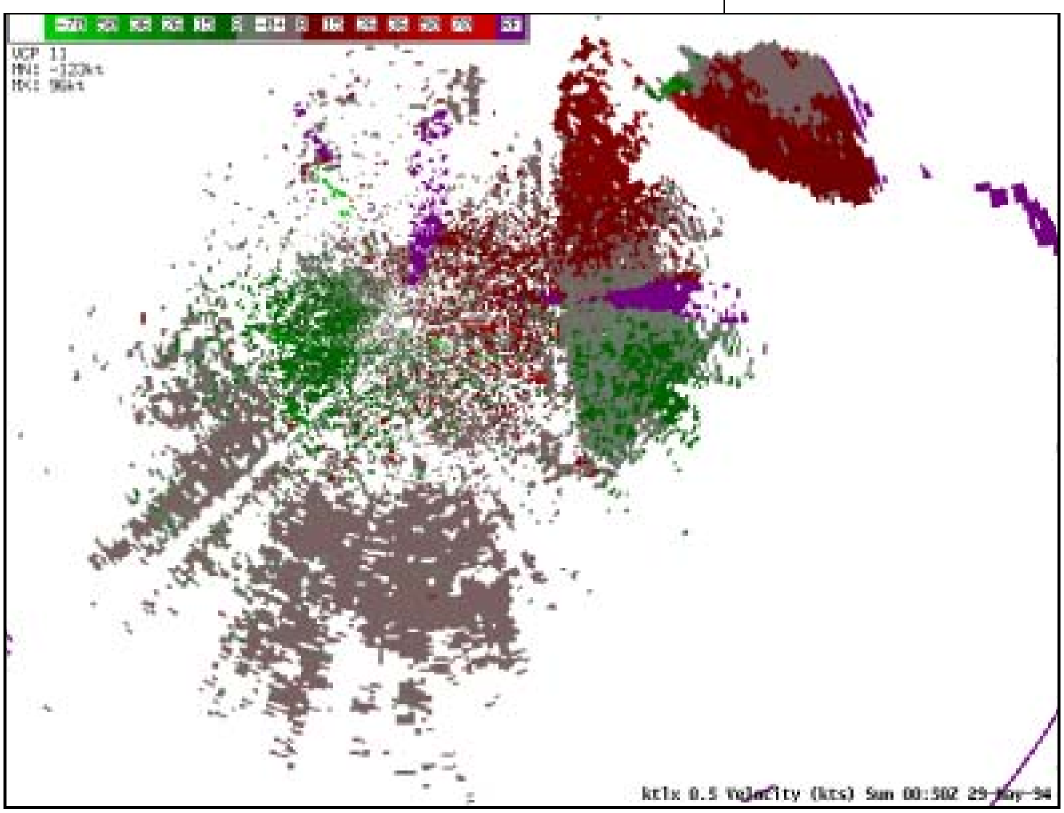


Figure 33. Example of anomalous propagation on the Base Velocity product corresponding to Figure 32. Note the field of near zero velocities with higher embedded values to the southwest of the RDA, as compared to the meteorological return to the northeast of the RDA.

Spectrum Width Products

Typically low spectrum widths

Just like normal ground clutter contamination, returns under superrefractive conditions are from ground targets, which are generally stationary. Thus, velocity dispersion is low, and spectrum width values will also be low. As with Mean Radial Velocity products, there are exceptions. Higher spectrum width values may result from leaves fluttering in trees, waves on the ocean, cars, etc. Larger structures can provide varying spectrum width values depending on the size of the structure relative to the range bin size and the speed of the flow around the structure. Anomalous Propagation on a Spectrum Width product is characterized by a general field of low spectrum widths with embedded higher values.

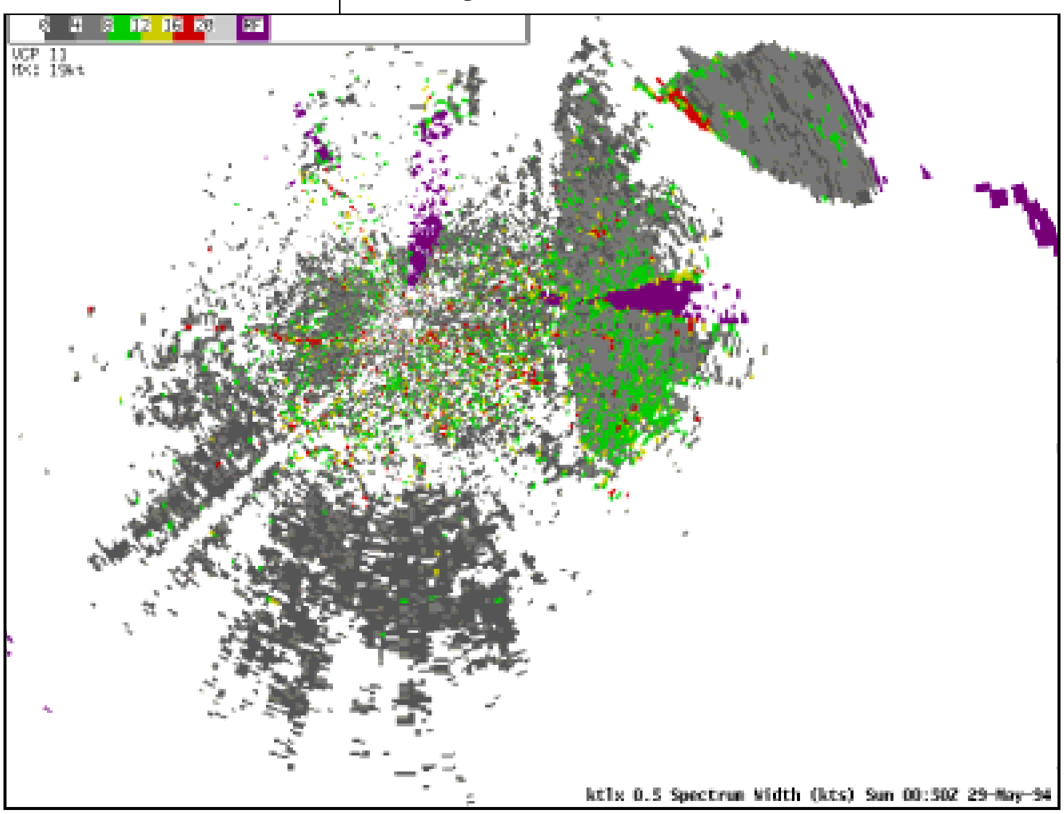


Figure 34. Example of anomalous propagation on the Base Spectrum Width product corresponding to Figure 32. Note the field of low spectrum widths with higher values embedded to the southwest of the RDA, as compared to the returns to the northeast of the RDA.

Ground Clutter Suppression

Reference

WSR-88D Clutter Suppression and Its Impacts on Meteorological Data Interpretation, J. Chrisman, D. Rinderknecht, R. Hamilton OSF/OTB; NWS EHB 6-521, Chapter 3-5

Clutter vs. meteorological signal

By examining ***both*** returned power and the velocity spectrum, we can distinguish between a meteorological and a clutter signal. A clutter signal will characteristically have high returned power, with radial velocities centered at zero and a narrow spectrum width. A meteorological signal will have varying returned power values, with the velocity rarely centered at zero.

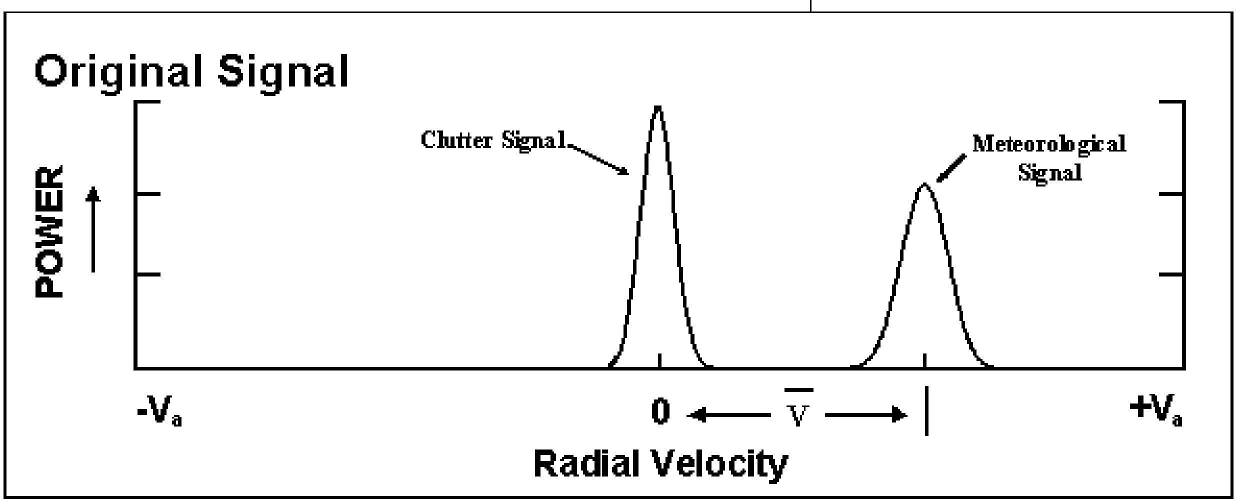


Figure 35. Doppler power spectrum depicting the Gaussian curve for a clutter vs. a meteorological signal within one range bin.

Remove clutter, retain meteorological return

By distinguishing the two types of signals from one another, the WSR-88D signal processor can extract meteorological information from range bins that are ground clutter contaminated. Clutter suppression filters are designed to reduce power ***only*** for signals whose velocity values are ***near zero***. Thus the ***remaining returns*** from meteorological targets are ***retained*** for the base data analysis for that range bin.

Notch Width

The notch width is an interval of velocities centerted on zero that defines which returned signals will be filtered. For example, if the notch width is set at 3.4 kts, then suppression will be applied to all signals whose velocities range from -1.7 to +1.7 kts. ***No suppression*** is applied to signals with velocities that are ***outside the notch width***.

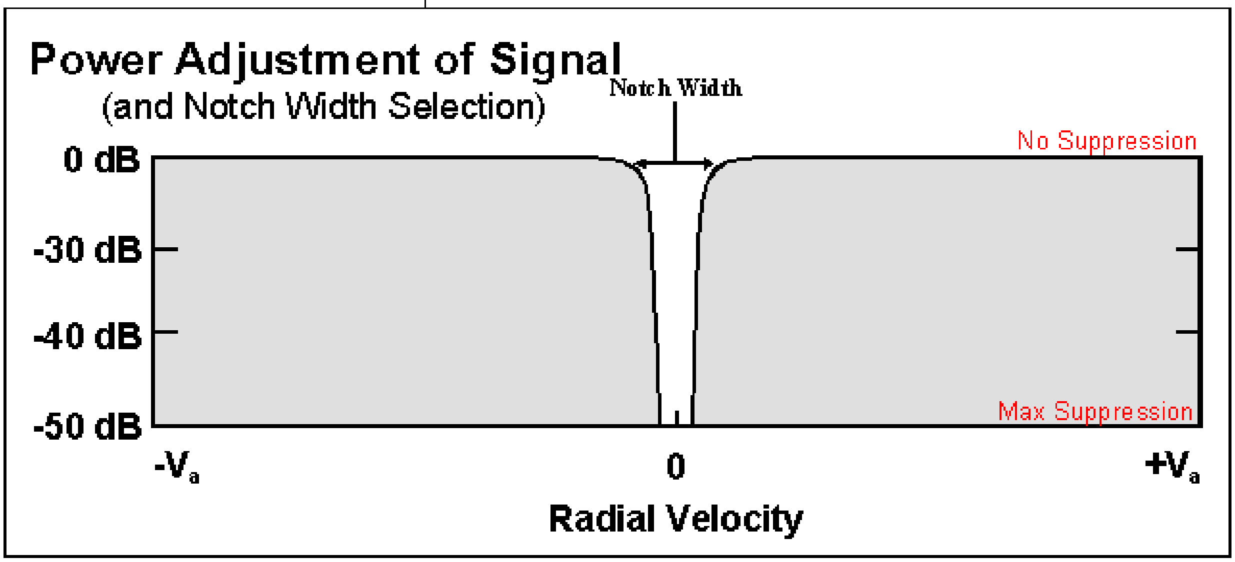


Figure 36. Removal process for the clutter signal. The narrowest portion of the clutter signal has the greatest signal removal.

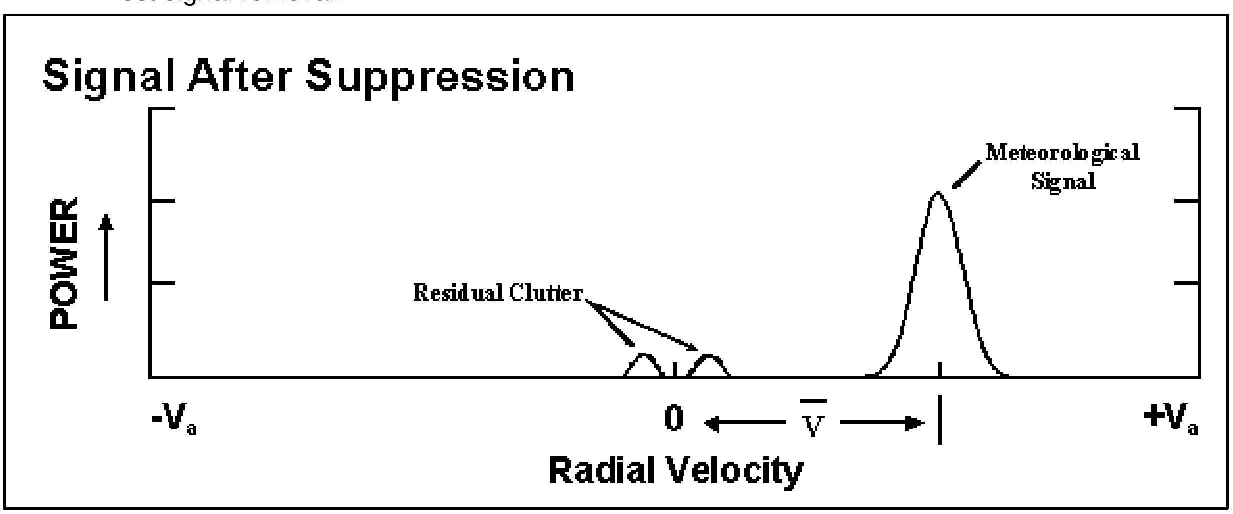


Figure 37. Doppler power spectrum for the range bin after suppression is performed. Note the residual clutter signal.

Residual clutter

Once the signal has been filtered, residual clutter may result in two ways:

1. The clutter filters can remove a limited amount of signal power. For example, mountains at

close range may return so much power that not all of the clutter signal can be removed.

2. Velocities associated with a clutter target (e.g. turbulence around buildings) may fall just outside the notch width, and thus the signal power is retained.

Examples of Residual Clutter

In the following examples, appropriate clutter suppression has been applied.

Base Refectivity

Note the erratically distributed, high reflectivity values near the RDA (Figure 38).

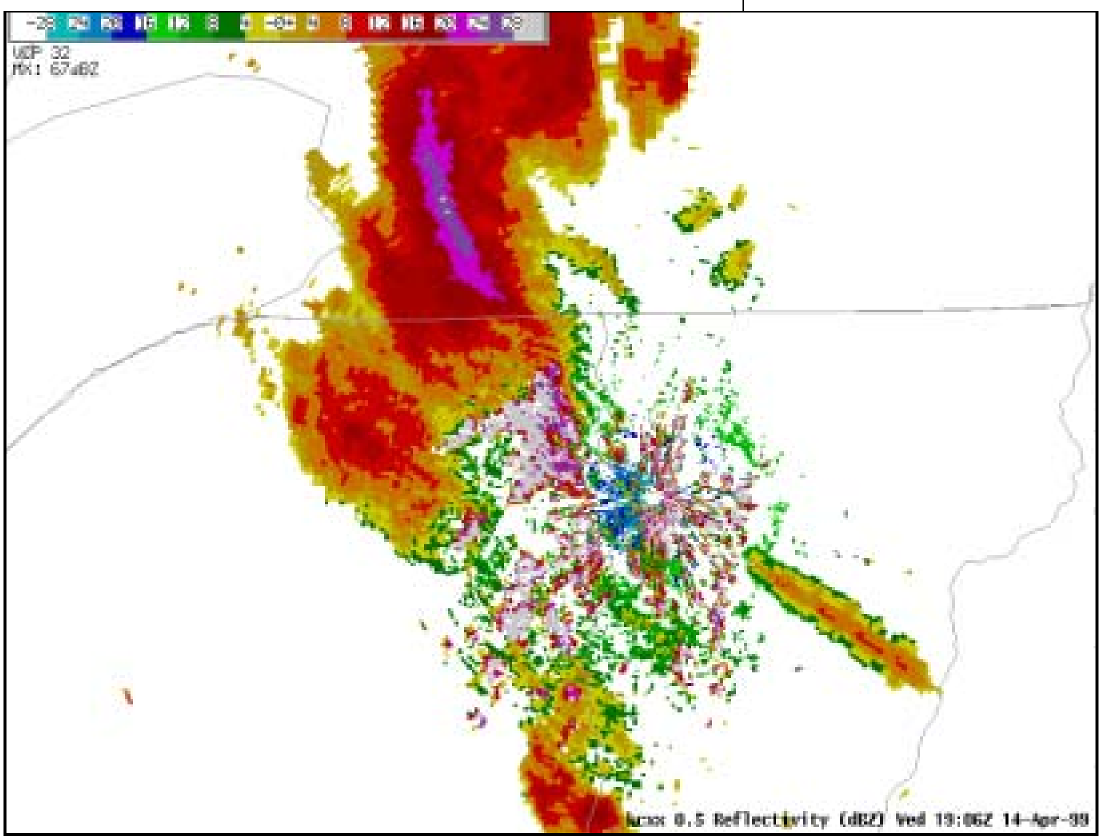


Figure 38. Example of residual clutter on a Base Reflectivity product.

Base Velocity

Note the concentration of near zero velocities close to the RDA (Figure 39).

Base Spectrum Width

Note the concentration of high spectrum width values near the RDA (Figure 40).

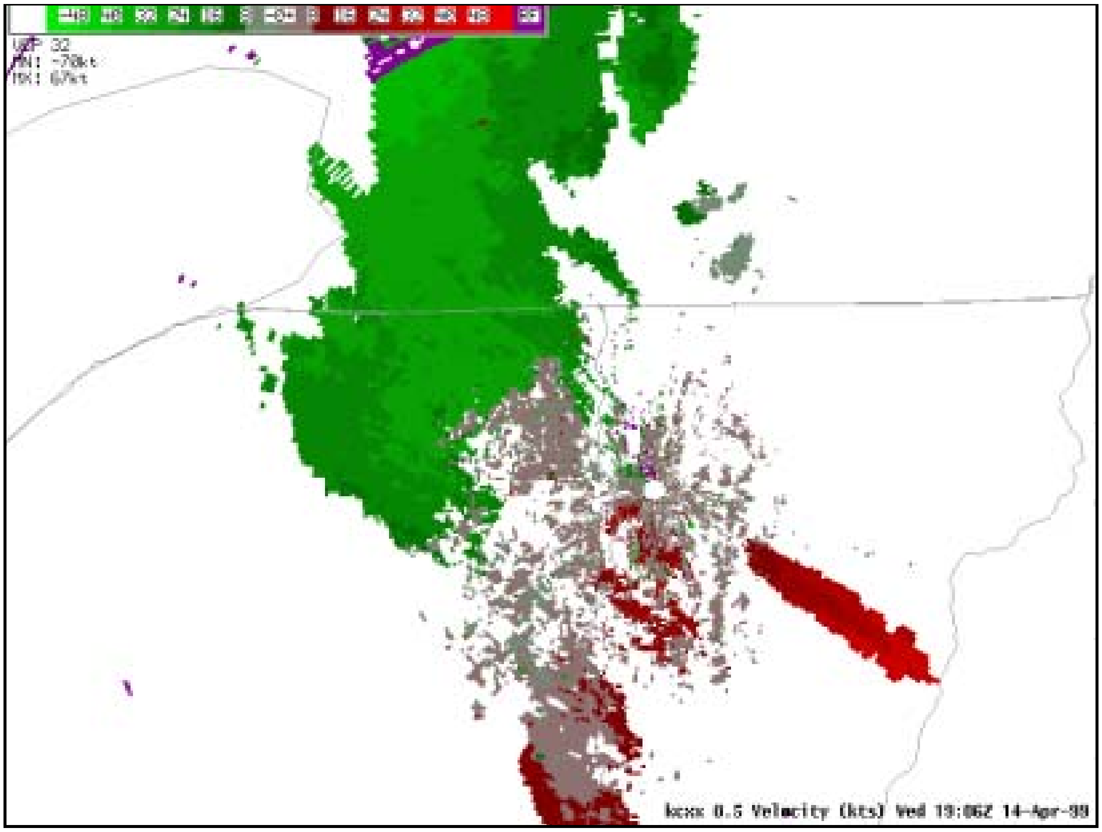


Figure 39. Example of residual clutter on a Base Velocity product.

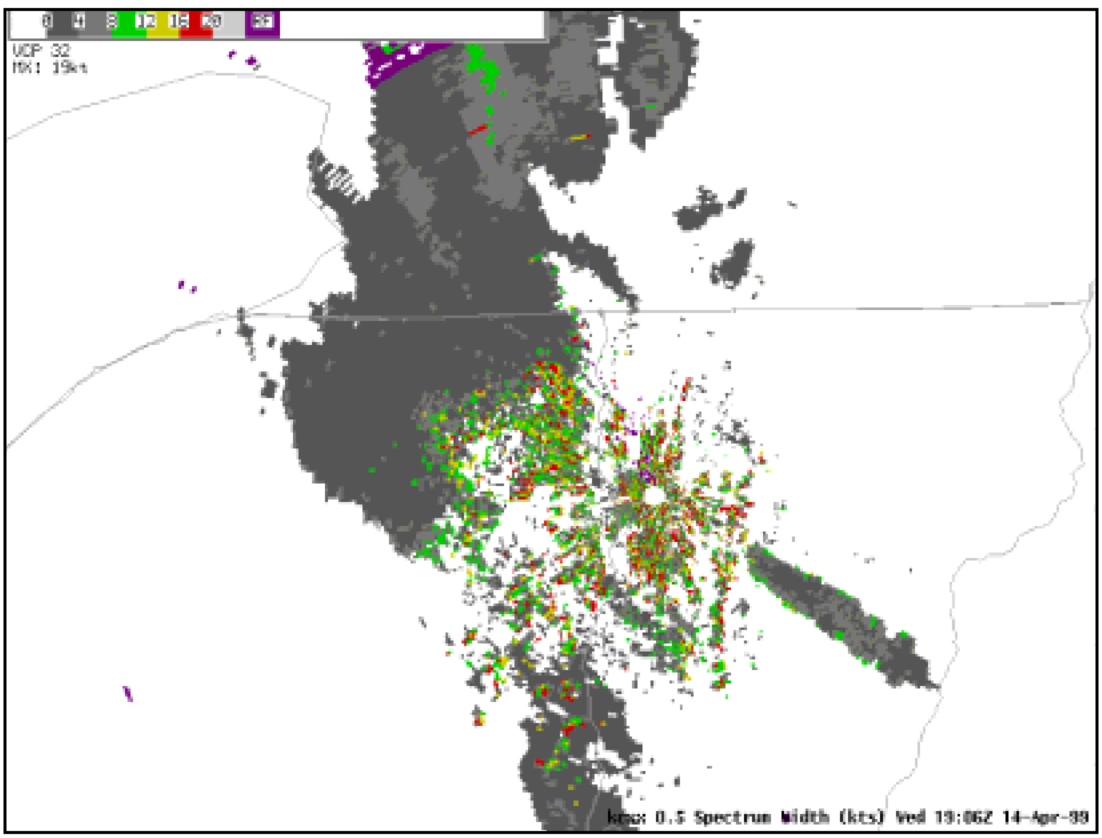


Figure 40. Example of residual clutter on a Base Spectrum Width product.

Removing most of the clutter signal will often have the effect of broadening the spectrum width.

Why is the spectrum width higher?

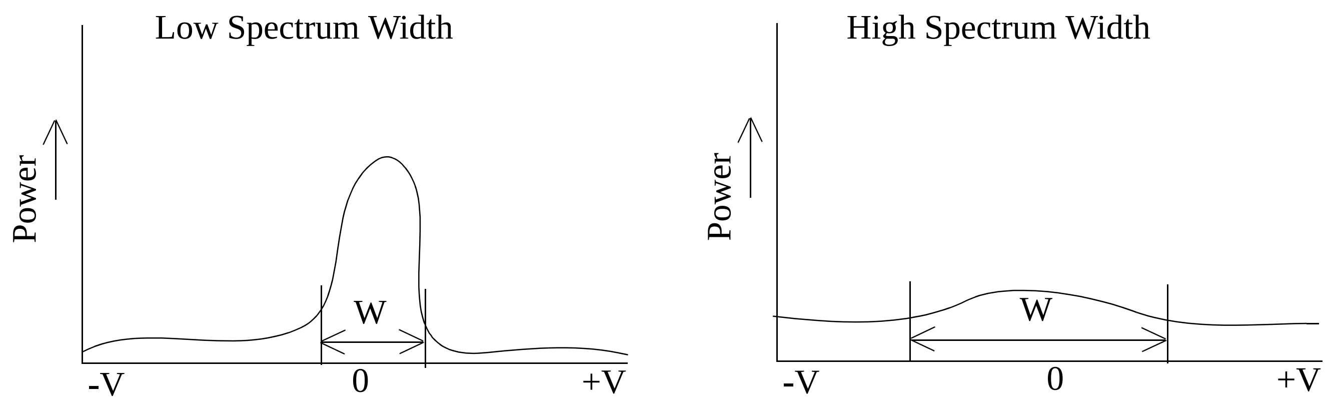


Figure 41. When the clutter "spike" is retained (left diagram), the spectrum width is low. When the clutter has been filtered (right diagram), the spectrum width is higher.

Application of Ground Clutter Suppression

RDASOT (RDA System Operability Test)

RDASOT is a program of numerous diagnostic techniques for many different purposes, one of which is Bypass Map generation. With respect to Bypass Map generation, the program is recommended to be rerun each season. For best performance, the Bypass Map should be generated when the atmospheric conditions are as near normal as possible for the particular site and the particular season.

Filtering of normal vs transient clutter

There are two different types of ground clutter, normal vs. transient, and therefore two different types of clutter filtering to address them. The Bypass Maps generated by RDASOT are designed to address ***normal*** ground clutter (mountains, buildings, etc.). Since the Bypass Maps identify the location of normal clutter targets, invoking the

Bypass Maps is appropriate for addressing ***normal*** ground clutter.

Transient ground clutter, anomalous propagation (AP), changes in both time and space, sometimes quite rapidly. The operator must designate the geographic area containing the AP that must be clutter filtered. This is done by creating a Clutter Suppression Region. Clutter filtering must be applied to every range bin throughout this region with a specified level of suppression. The selected level of suppression for the region will be applied to ***all*** targets with near zero velocities throughout the region. Inappropriate application of this type of clutter filtering can have adverse effects on products.

Clutter Filter Bypass Map(s)

RDASOT identifies the locations to apply suppression

By recognizing clutter signals, RDASOT identifies the ***location*** of ground clutter targets and generates maps identifying where suppression is to be applied.

Two maps are generated

Two maps are generated. The first map is used for the lowest 2 elevation angles. The second map is used for all the remaining elevation angles.

Polar grid structure

Both maps are polar grids with 1.4° x .54 nm bins. The maps specify which bins should have suppression applied.

The Bypass Map will ***only*** specify the ***location*** where suppression is to be applied. The ***amount*** of suppression to be applied is specified by the operator, or by employing the Default Notch Width Map.

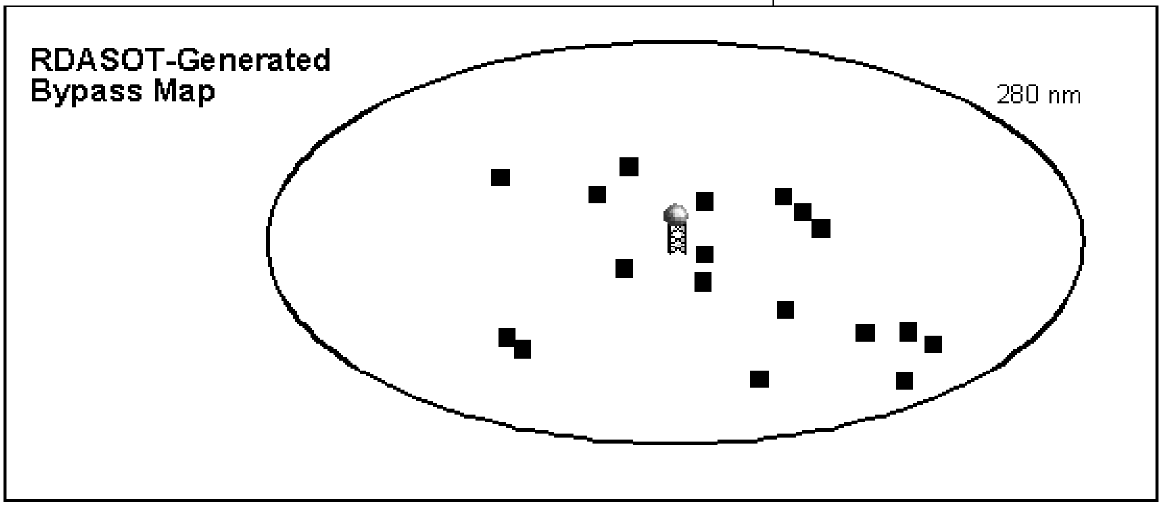


Figure 42. Clutter Filter Bypass Map. Note that individual bins identify where suppression is to be applied.

Default Notch Width Map(s)

A notch width is an interval of velocities centered on zero. For range bins where clutter filtering has been enabled, any portion of the returned signal that has a velocity within the notch width will be clutter filtered. There are three different notch widths and each of them has a different level of suppression (low, medium, or high) associated with it. See "Levels of Suppression (Notch Width)" on page 77 for example levels of suppression and their associated notch widths.

The Default Notch Width Map is used with the Bypass Map for areas where the operator has ***not*** defined clutter suppression. For range bins that are identified to receive clutter filtering by the Bypass Map, the Default Notch Width Map specifies medium suppression for the Surveillance channel and high suppression for the Doppler channel.

Operator Defined Clutter Suppression Regions

Clutter Suppression Regions are intended to customize the implementation of clutter suppression. The most effective clutter suppression is often the result of a combination of filtering for both normal and transient clutter.

Clutter Regions Filenames

Up to twenty Clutter Regions files can be defined. The filenames can be up to 31 characters long. Names that describe the type of clutter problem addressed by that file are recommended. For example, a file that has been defined to address frequent AP that forms within a valley could have that description as its filename.

There are 15 regions which can be defined within a given Clutter Regions file. For each region, the geographic area is defined, as well as the type of clutter filtering and the level of suppression.

Default File

One of the Clutter Regions files will always be the Default file. This is a permanently saved file that cannot be overwritten. The clutter configuration of this file has the Bypass Map in control for all azimuths and elevation angles. The levels of suppression are the same as with the Default Notch Width Map, i.e. medium suppression for the Surveillance channel and high suppression for the Doppler channel. Since this is assumed to be the default clutter configuration for most locations, the Default file exists to serve this function.

Clutter Regions Window

From the RPG Human Computer Interface (HCI), the Clutter Regions window is accessed by selecting the Clutter Regions button. See Figure 43.

The Clutter Regions window (Figure 44) has many features. When the window is initially opened, the clutter regions file displayed is the file most recently downloaded, i.e. currently in use.

The Clutter Regions window has two primary areas, the graphic display in the upper part of the

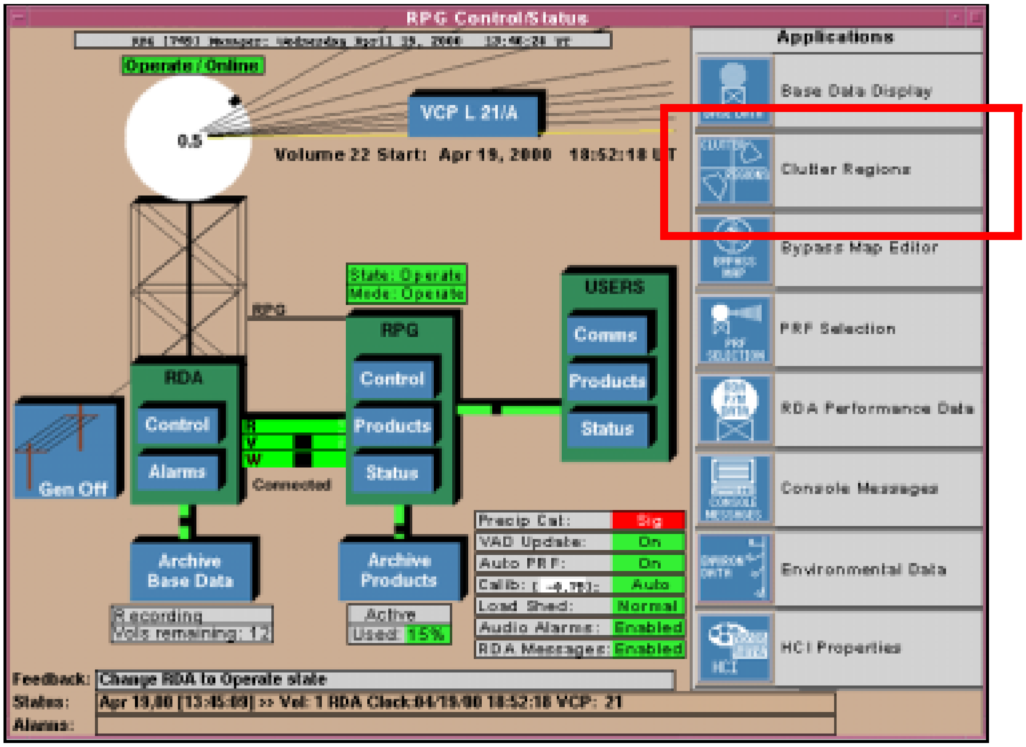


Figure 43. The RPG Human Computer Interface (HCI) with the Clutter Regions button highlighted.

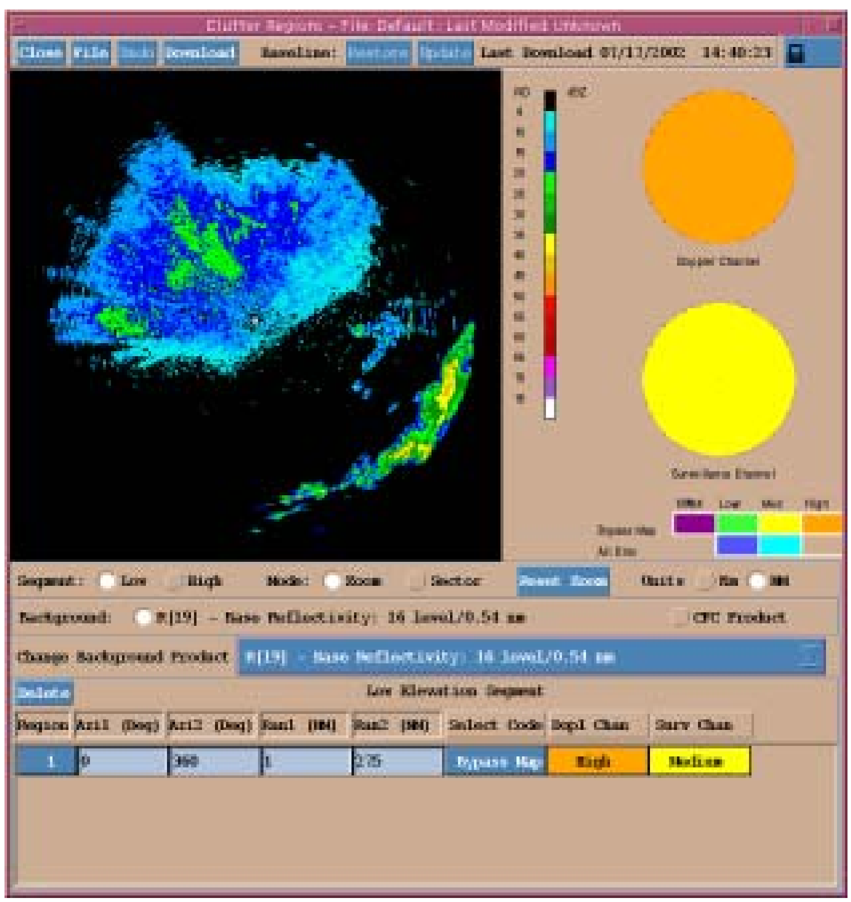


Figure 44. The Clutter Suppression Regions File editor window.

window and the table in the lower part. After choosing the desired background product for the graphical area, clutter suppression regions can be drawn using the mouse. Each geographic area that is drawn will have an associated line in the table. The table is then used to declare the type of suppression to be performed on that area, as well as the level of suppression for the Surveillance and the Doppler channels.

Elevation Segments

Clutter Regions can be defined for either the Low or High Segment. The low segment includes the elevation angles below 2.0° (0.5° and 1.5°), while the high segment includes the angles above 2.0°. Clutter filtering is not typically needed for angles above 2.0°, and should be used cautiously. See “Applying Select Code All Bins to the Batch Mode Elevations” on page 92.

Selecting a Background Product

There are a number of possibilities for the background product within the Clutter Regions window. Note that in Figure 44, the background product is Base Reflectivity (16 data levels, .54 nm). From the dropdown window, any of the following can be selected (Figure 45 and Figure 46):

- any of the 8 data level Base Reflectivity products (lowest elevation)
- any of the 16 data level Base Reflectivity products (lowest elevation)
- Clutter Likelihood Reflectivity (CLR)
- Clutter Likelihood Doppler (CLD)

The CLR and CLD products are generated by the Radar Echo Classifier Algorithm. See “Radar Echo Classifier” on page 72 for a description of this algorithm and examples of the products.

Figure 45. The Change Background Product dropdown menu. Note that 8 Data Level Base Reflectivity products (all three resolutions) could be selected.

Figure 46. The Change Background Product dropdown menu. Note that 16 Data Level Base Reflectivty products (all three resolutions), Clutter Likelihood Reflectivity or Clutter Likelihood Doppler could be selected.

Availability of Background Products

Product 19 (Base Reflectivity, 16 Levels, .54 nm), Clutter Likelihood Reflectivity, and Clutter Likelihood Doppler are on the default generation list. This means that these three products will be generated each volume scan and will be readily available.

The availability of the remaining products will depend on the current RPS list or any recent one time requests. If any of the these products is selected as a background product and it has not been generated, the initial response will be the message “Background Product Data Not Available” (Figure 47). A request will be sent to the RPG, and the product will be generated during the next volume scan. Once available, the product will ***not*** automatically display in the window. There are three ways to display the product, once it has been generated.

1. close, then reopen the Clutter Regions window, then select the desired product

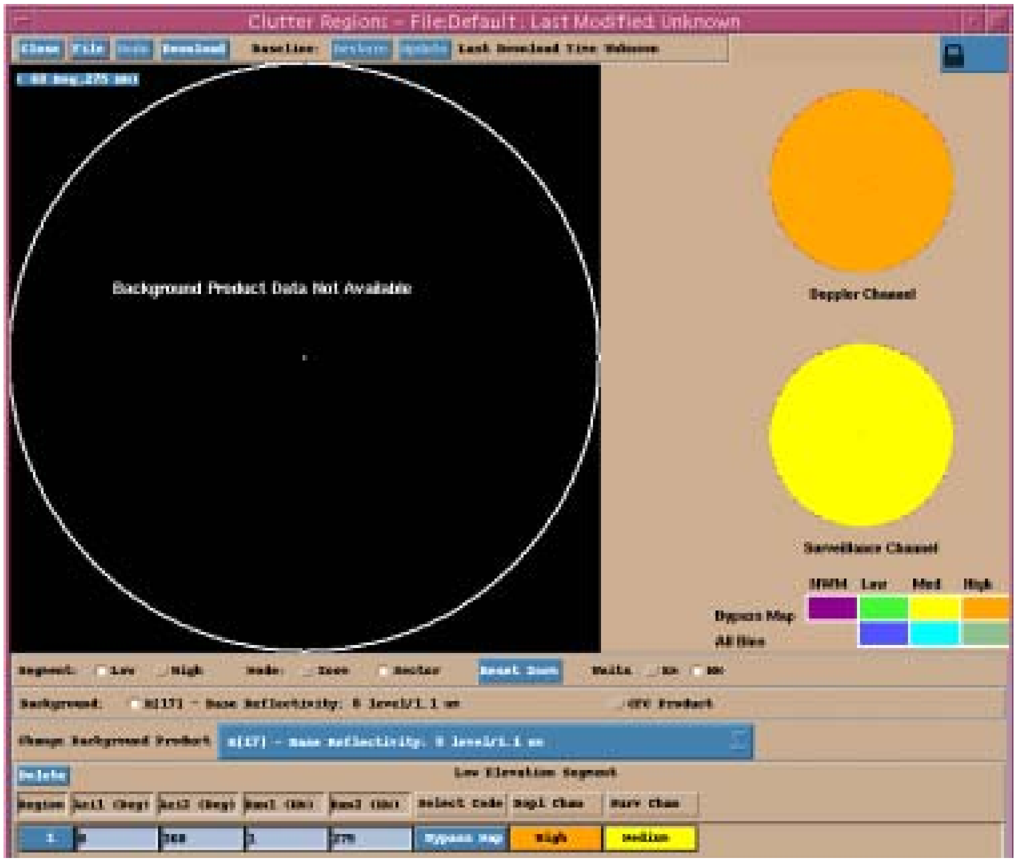


Figure 47. The Clutter Regions window when a background product that is currently unavailable has been selected. A request is sent to the RPG, and the product will be available next volume scan.

2. select a different background product, then select the original (desired) background product
3. switch from the current segment value (e.g. Low to High), then back again (High to Low)

Timeliness of Background Products

Once a background product has been displayed, it will ***not*** automatically update for subsequent volume scans. This is even true for the products that are generated every volume scan. If you are doing a lengthy clutter editing process, or are interrupted for a period of time while editing, you may need to reselect the background product to ensure its timeliness.

Radar Echo Classifier (REC)

The Radar Echo Classifier (REC) is an algorithm that performs fuzzy logic on the radar base data in real time. The objective of the REC is to determine the likelihood that the radar is detecting a certain category of target. Clutter is the current target category to be identified and additional modules may be added in later RPG Builds. For example, modules for the detection of precipitation, hail, and biological targets are under development.

To determine the likelihood of clutter for any particular range bin, the REC looks at the characteristics of the reflectivity, velocity, and spectrum width base data over a small area around that range bin.

Examples of REC Analysis of the Reflectivity Field

Clutter typically has high spatial variability in the reflectivity field. The REC looks at the mean of squared differences in the reflectivity values over a small area. A large mean can indicate clutter, but could also exist due to the high gradients in convective precipitation.

An additional step looks at the average of the sign of the changes. The absolute value of the sign change of reflectivity values within an area of clutter would typically be small compared to an area with a strong reflectivity gradient.

Examples of REC Analysis of the Velocity Field

The REC also looks at the velocity data for a small area around a given range bin. The absolute value of the mean velocity can be expected to be near zero for an area of clutter.

A likelihood of the existence of clutter, expressed as a percentage, is assigned to a range bin as the result of these (and other) indications from the reflectivity, velocity, and spectrum width fields.

The REC generates a product called Clutter Likelihood, with two versions:

- Clutter Likelihood Doppler (CLD). See Figure 48.

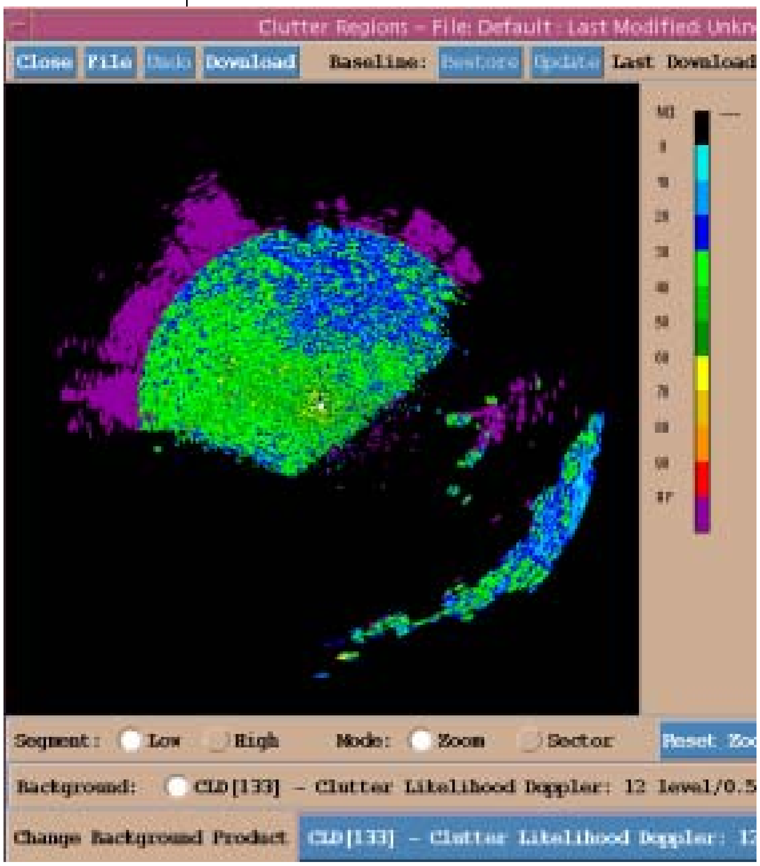


Figure 48. Clutter Likelihood Doppler (CLD) displayed as a background. Note the unavailability of probabilities in the range folded areas.

- Clutter Likelihood Reflectivity (CLR). See Figure 49.

These two examples correspond to the Reflectivity product in Figure 44, where AP exists over and to the northwest of the RDA and a line of showers exists to the southeast. The CLD will have the color purple assigned to range folded areas in the velocity field. The CLR will not have the purple, and thus could be used to examine clutter likelihood in areas that are range folded. However, since velocity data were ***unavailable*** for these areas, the REC results should be used with caution in range folded areas.

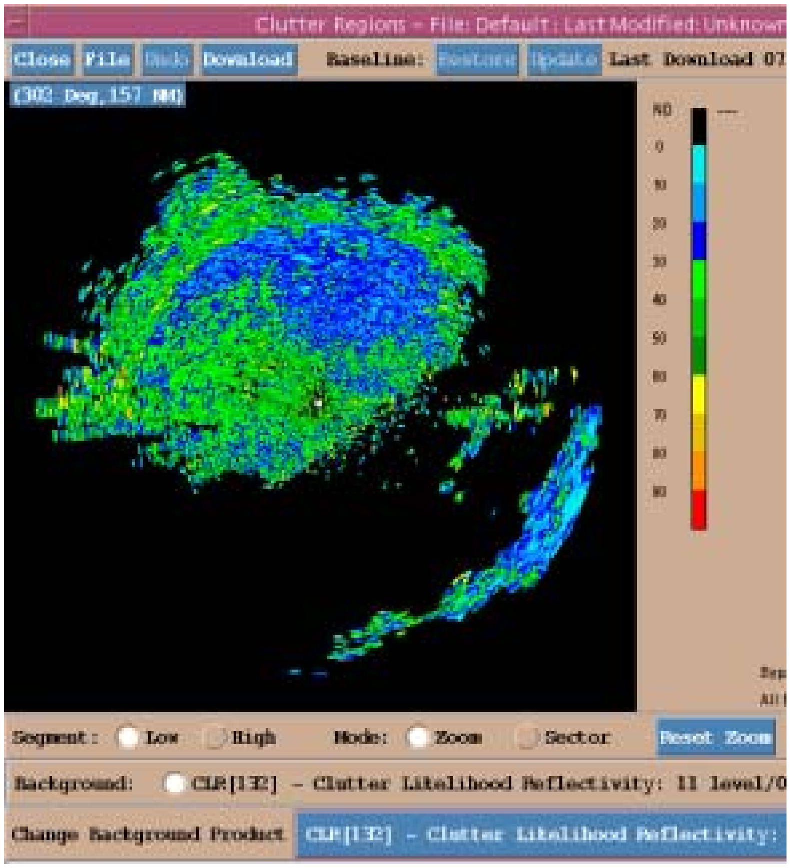


Figure 49. Clutter Likelihood Reflectivity (CLR) displayed as a background. Note generally lower probabilities within the area of precipitation and generally higher probabilities within the area of AP.

Clutter Regions Window

Tasks That Do Not Require a Password

It is not necessary to enter a password to edit an existing clutter regions file, to create a new file, or to download a file. In Figure 50, note that even though the padlock on the Clutter Regions window is locked, the File and Download buttons are enabled.

Figure 50. The Clutter Regions window when the password ***has not*** been provided. Note that the File and Download buttons are enabled.

Graphical Editor for the Geographic Region

The large graphical area of the Clutter Regions window is where the geographic regions for clutter filtering are defined (Figure 51). Once the background product is displayed, clutter regions can be drawn with the mouse (click and drag). The region is defined from azimuth to azimuth and from range to range. Acceptable azimuth values are from 0° to 360° and acceptable range values are from 1 to 275 nm. Once the mouse is released, a new line will appear in the table in the lower part of the window, depicting the azimuth and range coordinates of the region. You can edit the coordinates, or if you want to start over, use the delete button just above the table.

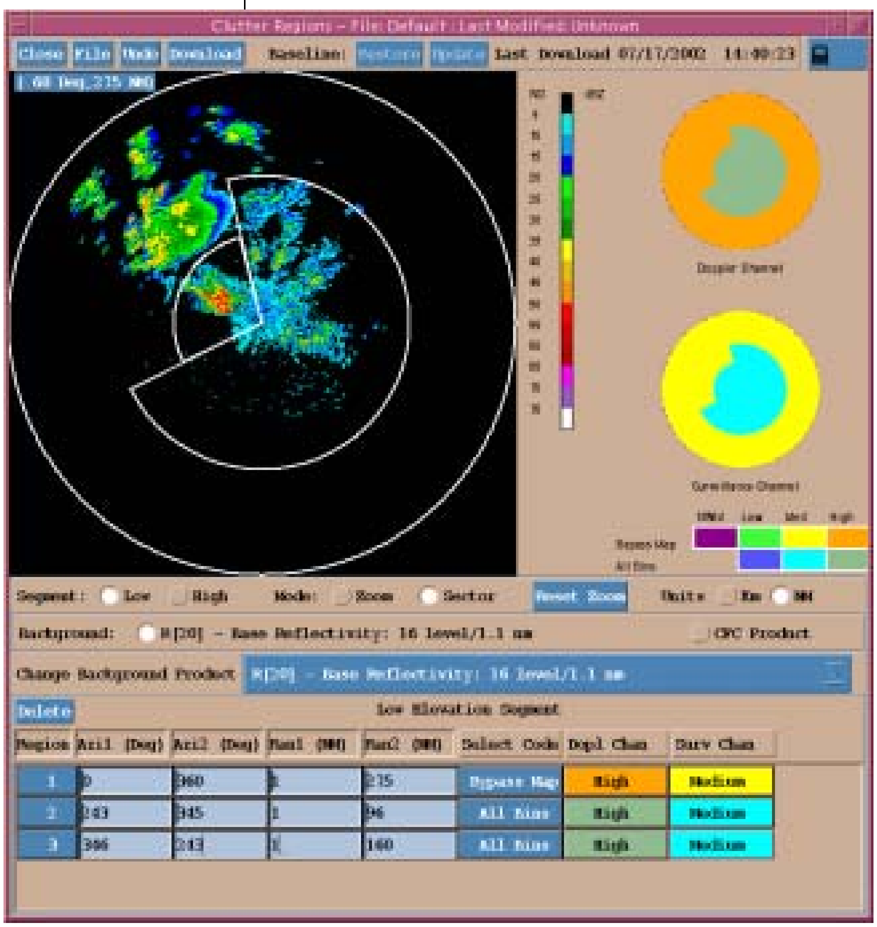


Figure 51. Editing a Clutter Suppression Regions File.

Types of Clutter Filtering

For the column entitled “Select Code”, there are three types of clutter filtering from which to choose.

- **Bypass Map** - Clutter filtering will be performed ***only*** on those range bins identified by the Bypass Map within the defined geographic region. The level of suppression (low, medium, or high) is specified by the operator. Bypass Map is the appropriate type of clutter filtering for normal ground clutter.
- **All Bins** - Clutter filtering will be performed on ***every*** range bin within the defined geographic region. The level of suppression (low, medium, or high) is specified by the operator. All Bins is the type of clutter filtering appropriate for AP.
- **None** - Clutter filtering will ***not*** be performed ***anywhere*** within the defined geographic region. Though this option would be used very rarely, it may be instructive to use None for a very short time in order to better identify a clutter problem at a particular site.

Levels of Suppression (Notch Width)

The “Dopl Chan” and “Surv Chan” columns are for designating the level of suppression. Each of the three levels (low, medium, or high) has an associated notch width, which is an interval of velocities around zero that will have their associated signal power reduced (suppressed). The levels of suppression are applied ***separately*** to the Surveillance and Doppler Channels. The following suppression levels and associated notch widths apply to the lowest two elevation angles, where the Split Cut (CS/CD) mode is used.

- **Low Suppression** - approximately 30 dB power reduction. The Notch Width is about 3.4 kts, or ±1.7 kts.

- **Medium Suppression** - approximately 40 dB power reduction. The Notch Width is about 4.8 kts, or ±2.4 kts.
- **High Suppression** - approximately 50 dB power reduction. The Notch Width is about 6.8 kts, or ±3.4 kts.

Power Removed is an Approximation

The amount of power that is actually suppressed for any level, as well as the notch width, is an approximation. The exact value will change depending on antenna rotation rate, which varies with VCP and elevation angle. Notch widths are significantly wider for the elevation angles that employ Batch (B) mode (between 2° and 7° for VCPs 11, 21, and 32). Clutter filtering should ***not*** be applied to these elevations unless absolutely necessary. See "Applying Select Code All Bins to the Batch Mode Elevations" on page 92.

Clutter Editor Legend

In Figure 52, note that the Bypass Map levels of suppression include a purple box that is labeled NWM.

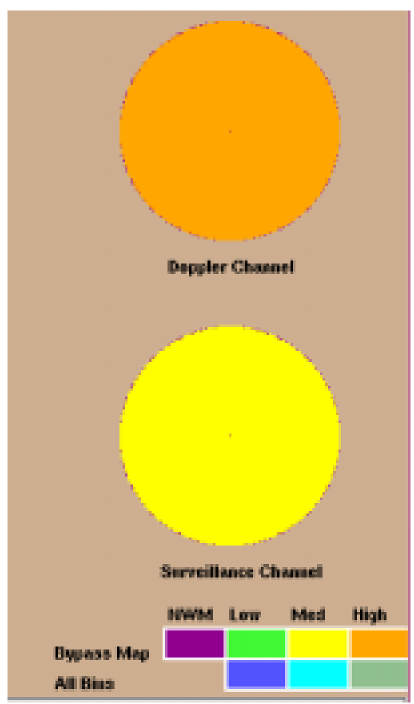


Figure 52. The Clutter Regions window legend.

Default Notch Width Map

NWM is a reference to the Default Notch Width Map. Recall that a notch width is an interval of velocities centered on zero which corresponds to a level of suppression. Any portion of the returned signal that has a velocity value that falls within the notch width will be clutter filtered. There are three different notch widths, each having a different level of suppression (low, medium, or high).

The Default Notch Width Map, when invoked, applies medium suppression to the Surveillance channel and high suppression to the Doppler channel. The Bypass Map will define the geographic locations for filtering to occur.

In the Clutter Regions window, the Default Notch Width Map is invoked by deleting all the lines in the table at the bottom of the window. This creates a file with no operator specified clutter suppression. The default clutter suppression scheme has the Bypass Map dictating the location for clutter filtering and the Default Notch Width Map dictating the level of suppression.

In the legend area of the window, the circles for the Doppler and Surveillance channels will be colored purple to denote this default condition. This “blank” file could be saved and downloaded in order to invoke this default condition.

Clutter Region Files Window Features That Do Not Require a Password

Without providing a password, the Clutter Region Files window allows you to create a new file or to display a previously defined file (Figure 53). In either case, you may also edit the file without entering a password. The design allows for quick editing to deal with a clutter problem that is not addressed by an existing file within the Baseline Set.

Figure 53. The Clutter Region Files window when the password ***has not*** been provided.

Save or Save As

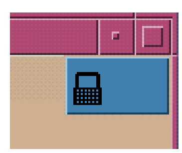
Note that the "Save As" button is enabled in Figure 53, while the "Save" button is not. This is to prevent an operator from inadvertently overwriting an existing file.

Downloading

In order to invoke the clutter filtering specified in a Clutter Regions File, the file ***must be downloaded to the RDA***. It will then be invoked at the beginning of the next volume scan. This file will remain in effect until another file is downloaded.

Tasks That Do Require a Password

The padlock in the upper right of the Clutter Regions window indicates that some edits in this window have a Level of Change Authority (LOCA) that requires a password.



Password protected edits in the Clutter Regions window are under the Unit Radar Committee (URC) LOCA. Clicking on the padlock will open the password window (Figure 54).

Once the URC password is entered, the padlock on the Clutter Regions window will be open. Tasks that require a password include editing and over-

Figure 54. The Password window.

writing an existing file, and making changes to the Baseline Set. Note that in Figure 55 the “Baseline Set” buttons have been enabled.

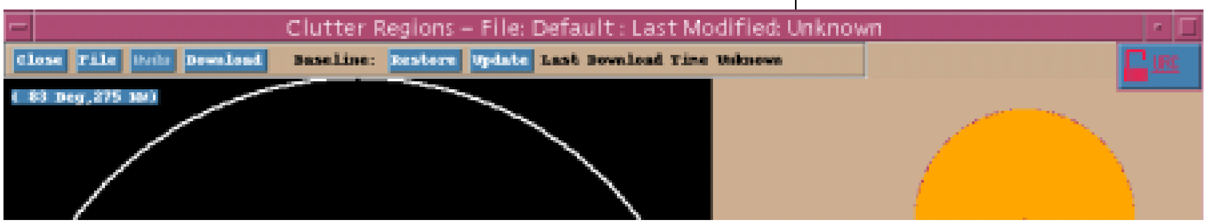


Figure 55. The Clutter Regions window when the password ***has*** been provided. Note that the Baseline Set buttons are enabled.

Baseline Set of Files

The Baseline Set of files is designed to provide a group of clutter regions files available for a variety of clutter suppression needs. Managing the Baseline Set will require knowledge of two important buttons on the Clutter Regions window.

Update

Selecting Update will update the Baseline Set of files to include any newly defined and saved files.

Restore

Selecting Restore will reload the most recently updated Baseline Set of files. Any new file that has been defined and saved but is ***not*** yet part of the baseline set ***will be lost***.

New files that have been defined and saved are available for downloading or editing as long as the Restore button has ***not*** been selected.

Clutter Region Files Window Features That Do Require a Password

When the password has been provided, there are also changes to the Clutter Region Files window. See Figure 56.

Figure 56. The Clutter Region Files window when the password ***has*** been provided.

Note that the “Save” and “Delete” buttons are now enabled (the Save button will be enabled once any change is made in the editing window). This allows for edits and adjustments to the Baseline Set. Once any necessary changes are made to the files within this set, the Update button ***must*** be used to include these changes to the Baseline Set.

Final Caution

Caution is required if there is a full set of 20 files already saved. It may then be possible to overwrite one of the existing files.

Figure 57. The Clutter Regions Filename window.

It is also possible to save multiple files to the same filename. The following scenario ***only*** applies to steps taken during the ***same*** editing session. In the Clutter Region Files window, it is typical to type a filename and then select the accept button. If the accept button is selected without first entering a filename, the file is saved using the previously entered filename. If repeated, this can result in saving multiple files to the same filenames.

Examples of Data With and Without Proper Clutter Filtering

The following examples of WSR-88D products illustrate the effective use of clutter suppression. In Figure 58 and Figure 59, a boundary is embedded in an area of unsuppressed AP. Portions of the boundary are unidentifiable, particularly in the velocity data.

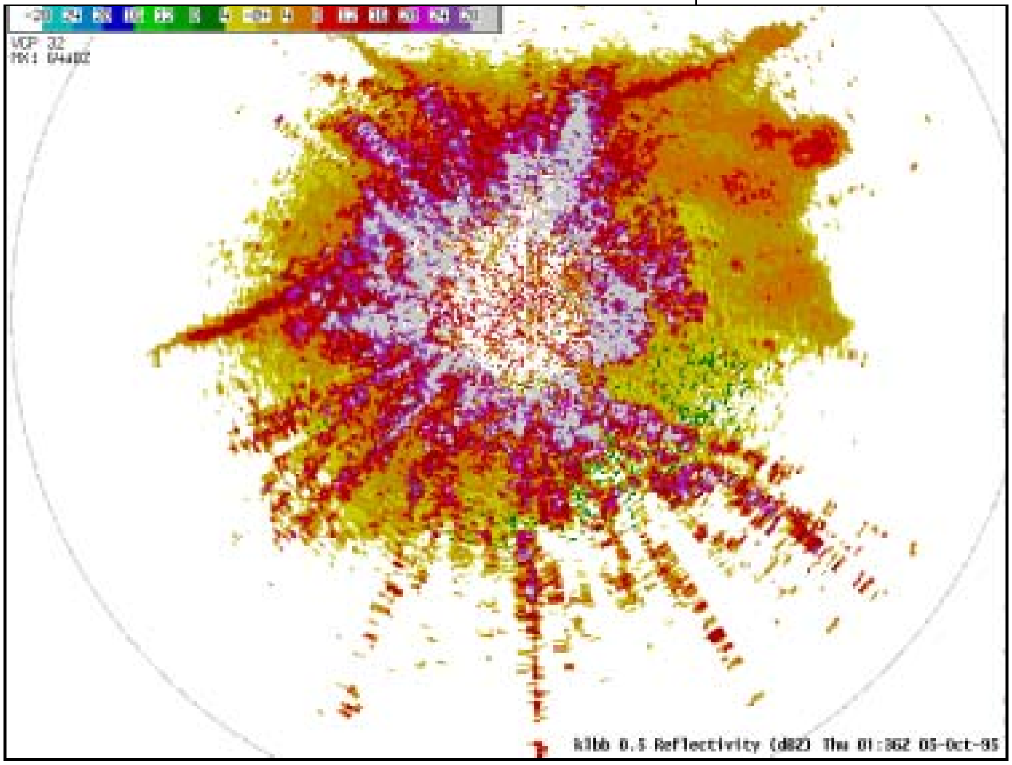


Figure 58. There is a boundary embedded in the AP in this Reflectivity product. No clutter filtering has been applied to suppress the AP.

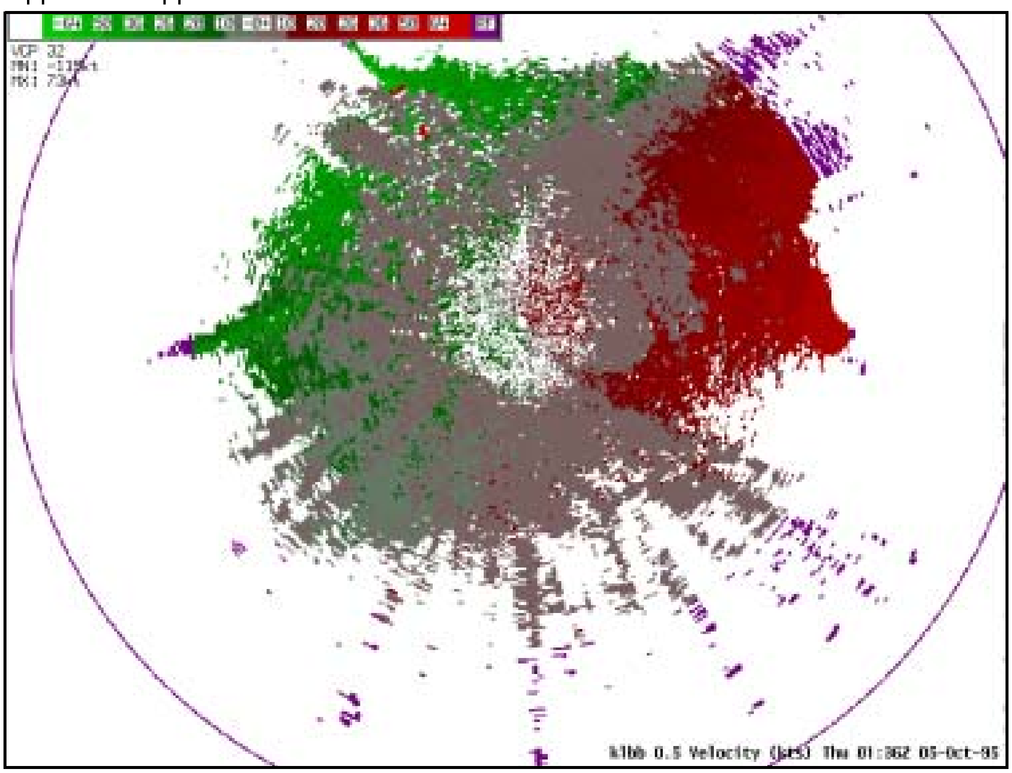


Figure 59. This is the Velocity product associated with Figure 58. No clutter filtering has been applied to suppress the AP.

In Figure 60 and Figure 61, the AP has been suppressed. The boundary is now much more apparent and the surrounding data are also now available for interpretation.

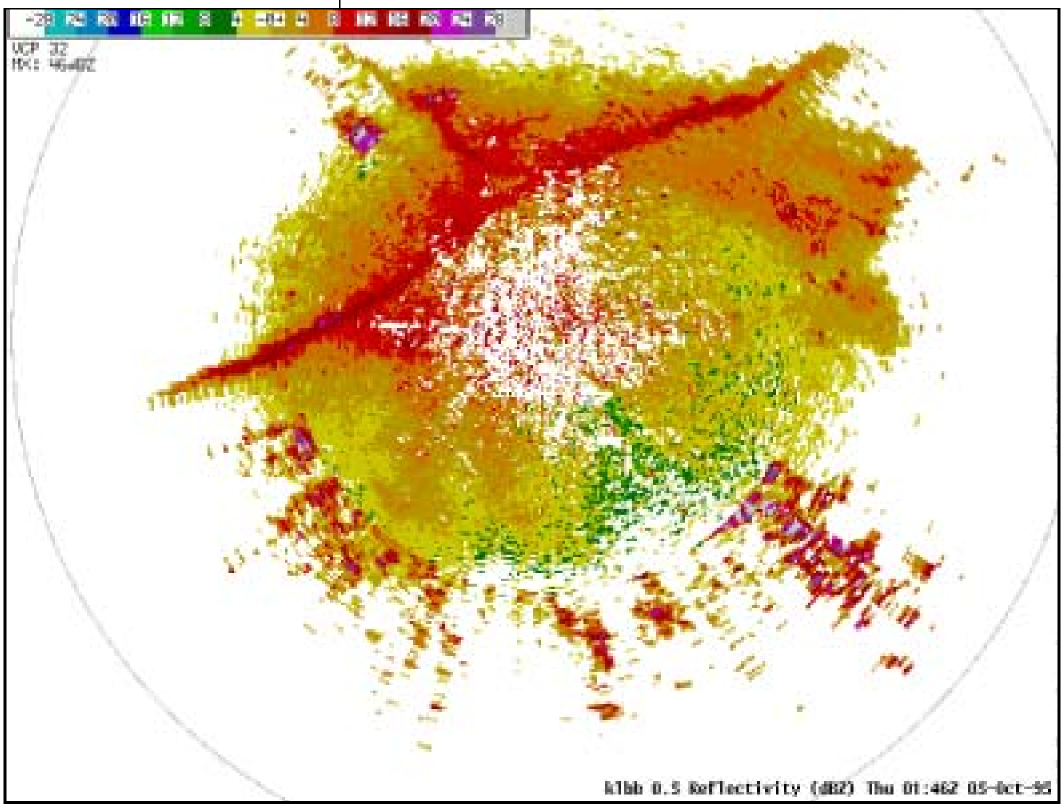


Figure 60. Once proper clutter filtering has been applied, the boundary is easily identified.

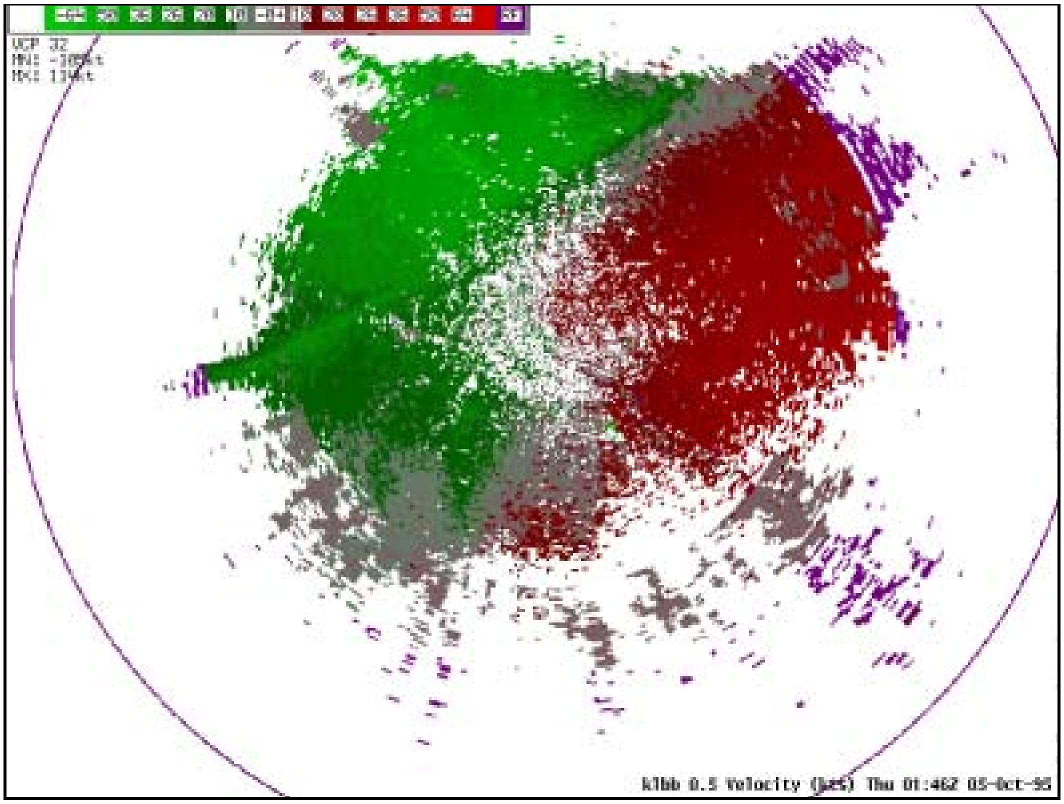


Figure 61. This is the Velocity product associated with Figure 60. Note the improved quality of the velocity estimates throughout the area once filtering is applied.

Clutter Filter Control (CFC) Map

This product (Figure 63) graphically demonstrates the clutter filtering configuration currently in effect at the RDA.

Product Display

Depending on the parameters selected (Figure 62), there are four possible product versions, which are differentiated by the following:

1. Surveillance or Doppler Channel
2. Elevation Segment Number 1 or 2

Elevation Segment 1 corresponds to the Low Segment, while Elevation Segment 2 corresponds to the High Segment.

Figure 62. Clutter Filter Control one time request.

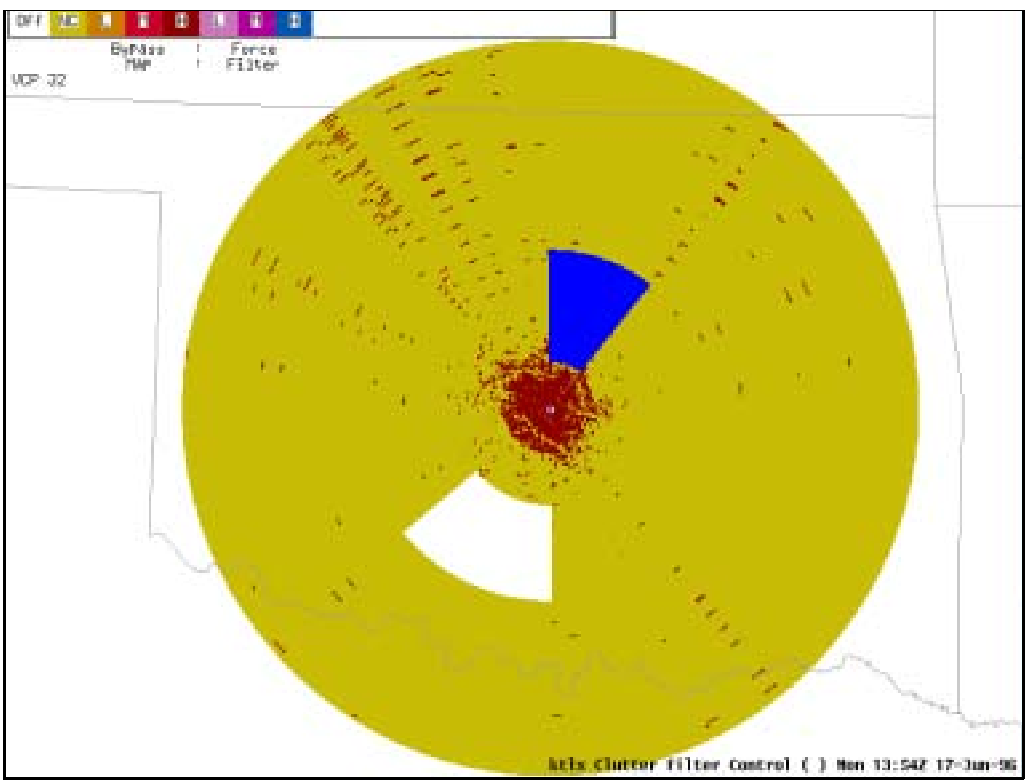


Figure 63. Example of the Clutter Filter Control product.

WSR-88D Data Examples

In the following examples, different types of clutter suppression (different select codes) have been invoked.

Select Code None

In Figure 64 and Figure 65, clutter filtering has been disabled over the entire radar coverage area.

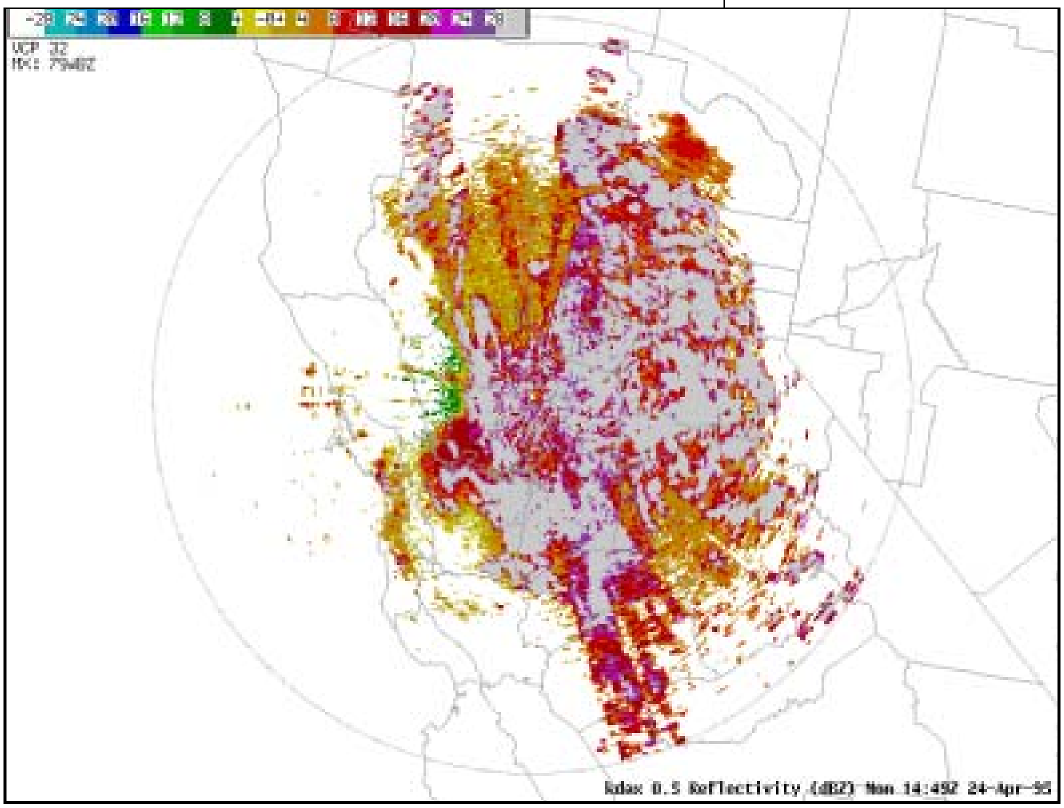


Figure 64. Base Reflectivity with Select Code None applied for the entire radar coverage area, turning off all clutter suppression.

Select Code Bypass Map

In Figure 66 and Figure 67, the Clutter Filter Bypass Map is in control, identifying the locations for suppression, while the amount of suppression is identified by the operator. Though the clutter bias to the east and west has been reduced, note that clutter contamination oriented north to south remains. This is due to AP in the valley.

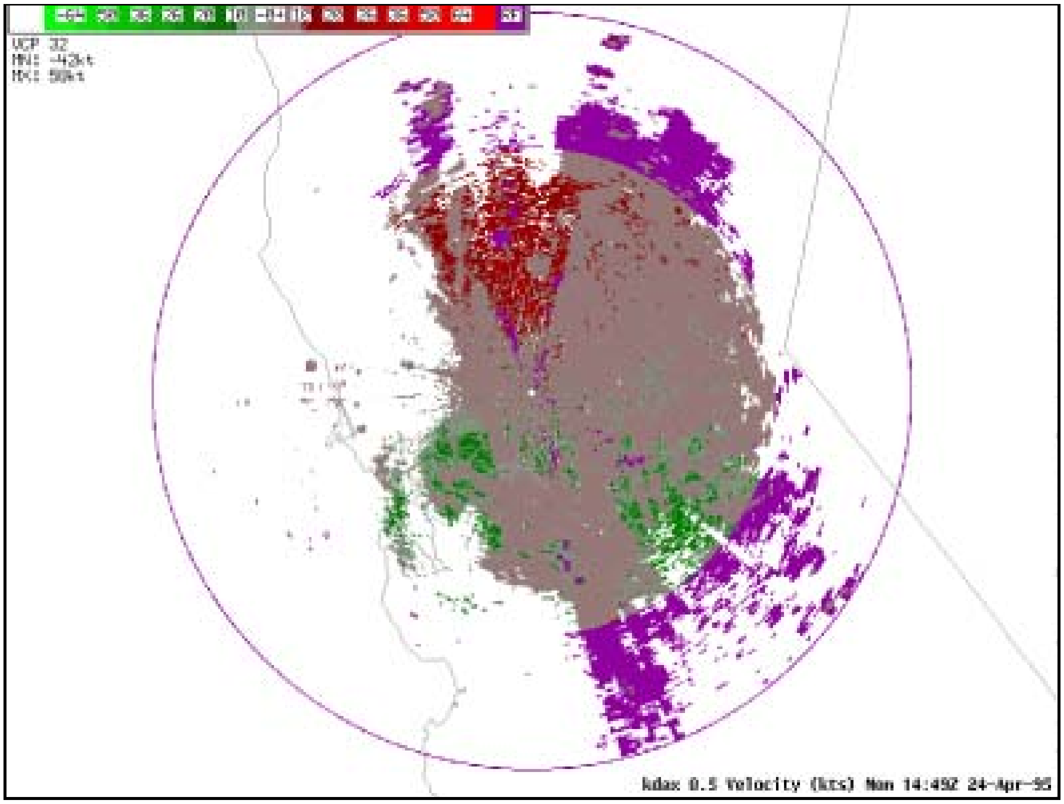


Figure 65. Base Velocity with Select Code None applied for the entire radar coverage area, turning off all clutter suppression. Note the large area of near zero velocities due to clutter bias.

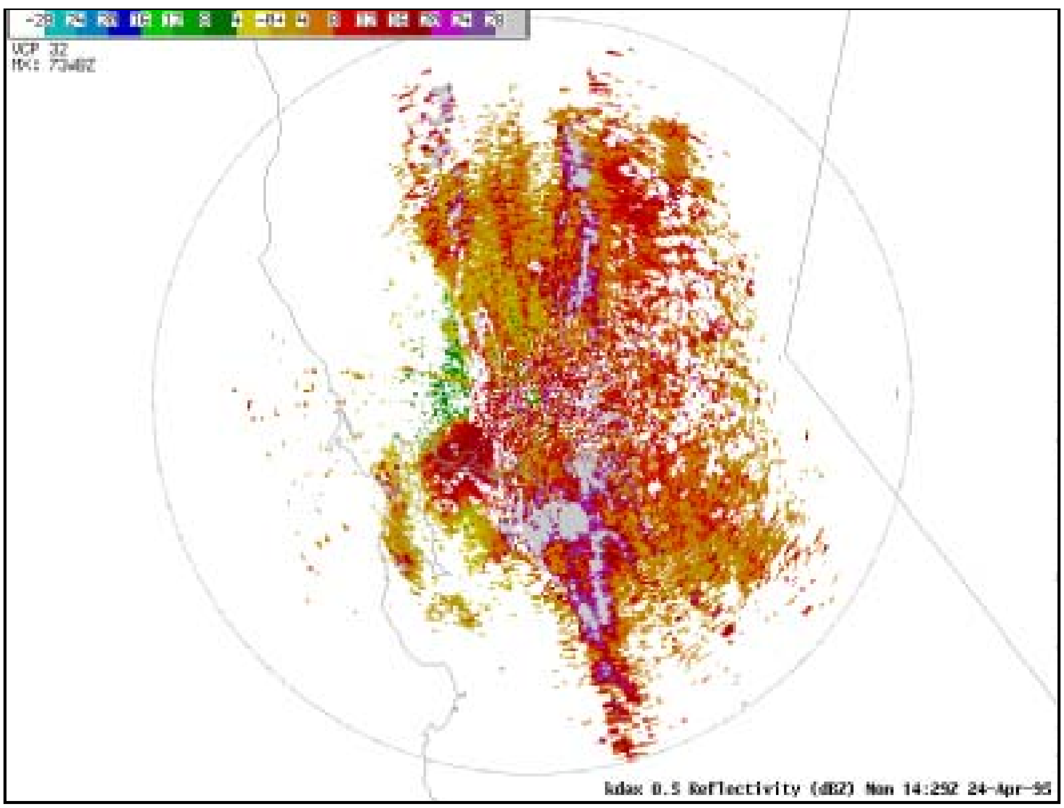


Figure 66. Base Reflectivity with Select Code Bypass Map applied for the entire radar coverage area. Note the high reflectivities, caused by AP, remaining from north to south.

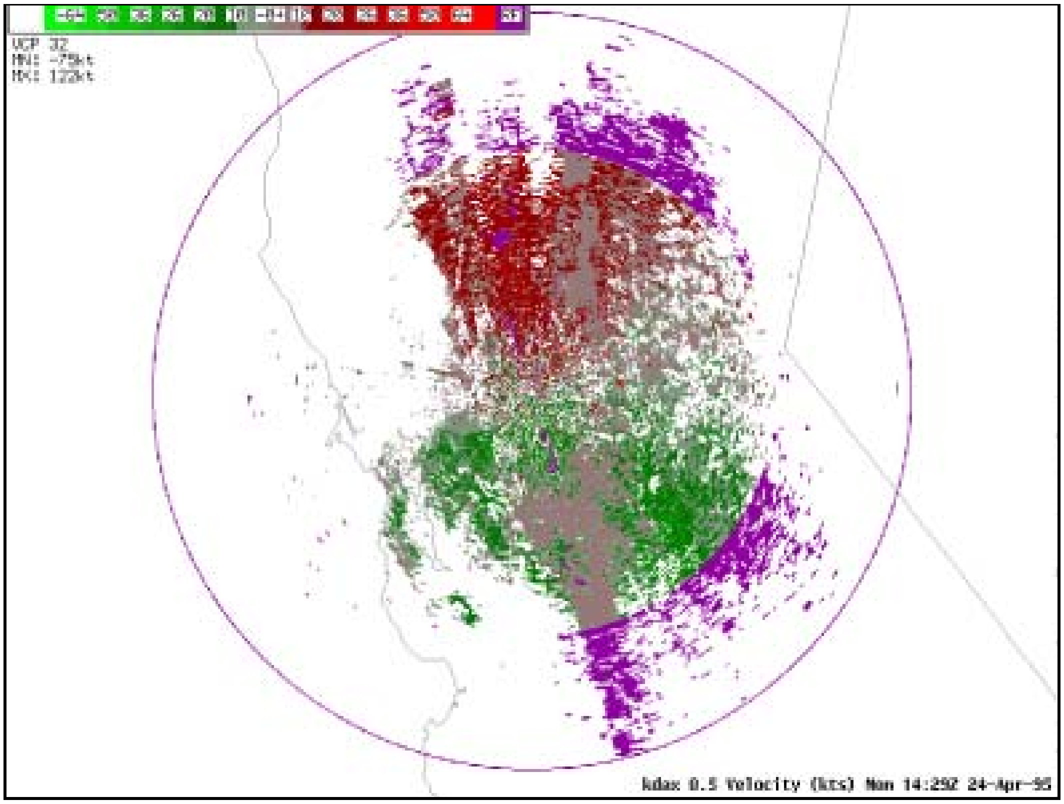


Figure 67. Base Velocity with Select Code Bypass Map applied for the entire radar coverage area. Note the near zero velocities, caused by AP, remaining from north to south.

Select Codes Bypass Map and All Bins Combined

In Figure 68 and Figure 69, Select Code All Bins is in effect to the north and south to filter out AP in the valley, while Select Code Bypass Map remains in control elsewhere.

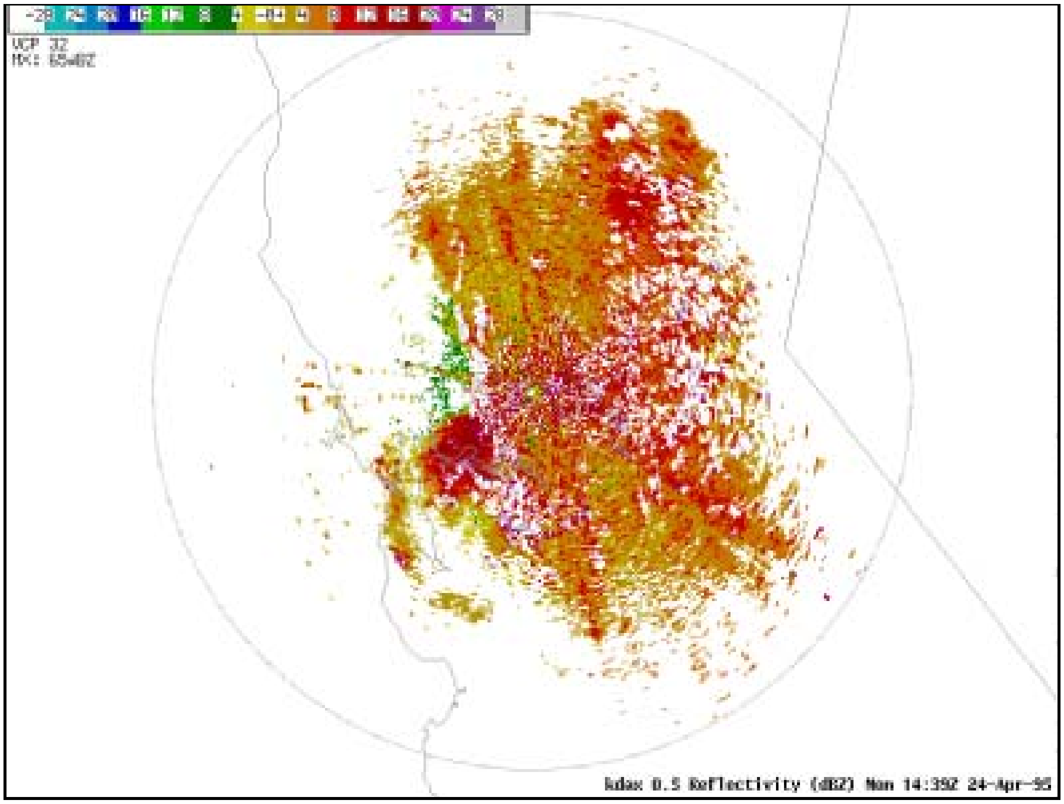


Figure 68. Base Reflectivity with Select Code Bypass Map to address normal ground clutter and Select Code All Bins to eliminate the AP in the valley (north to south).

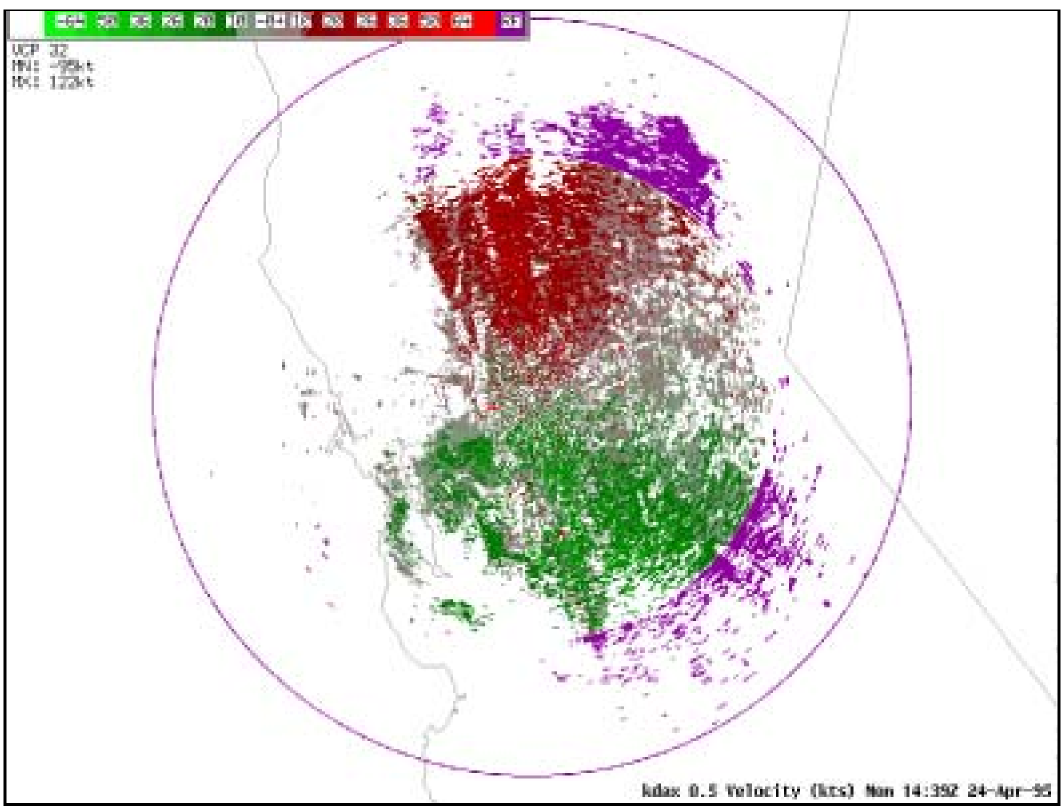


Figure 69. Base Velocity with Select Codes Bypass Map and All Bins applied, corresponding to Figure 68.

Negative Effects When Select Code All Bins is Inappropriately Applied

Select Code All Bins is a powerful tool for AP suppression, since this phenomena is highly variable in space and time. However, employing Select Code All Bins for long term removal of non-transient ground returns is inappropriate and will produce the following adverse effects on products.

Zero Isodop Evident on Reflectivity-Based Products

Recall that clutter filtering will reduce power ***only*** from radar returns with a near zero radial velocity. When Select Code All Bins is employed within a region, then ***every*** returned pulse within that region with zero to near zero velocity will be filtered. The result on the Reflectivity product is an area of reduced reflectivities that corresponds to the area of near zero velocity on the Mean Radial Velocity product. This reduction in power for the reflectivity estimation will also have a detrimental effect on all Reflectivity-based products. See Figure 70 and Figure 71.

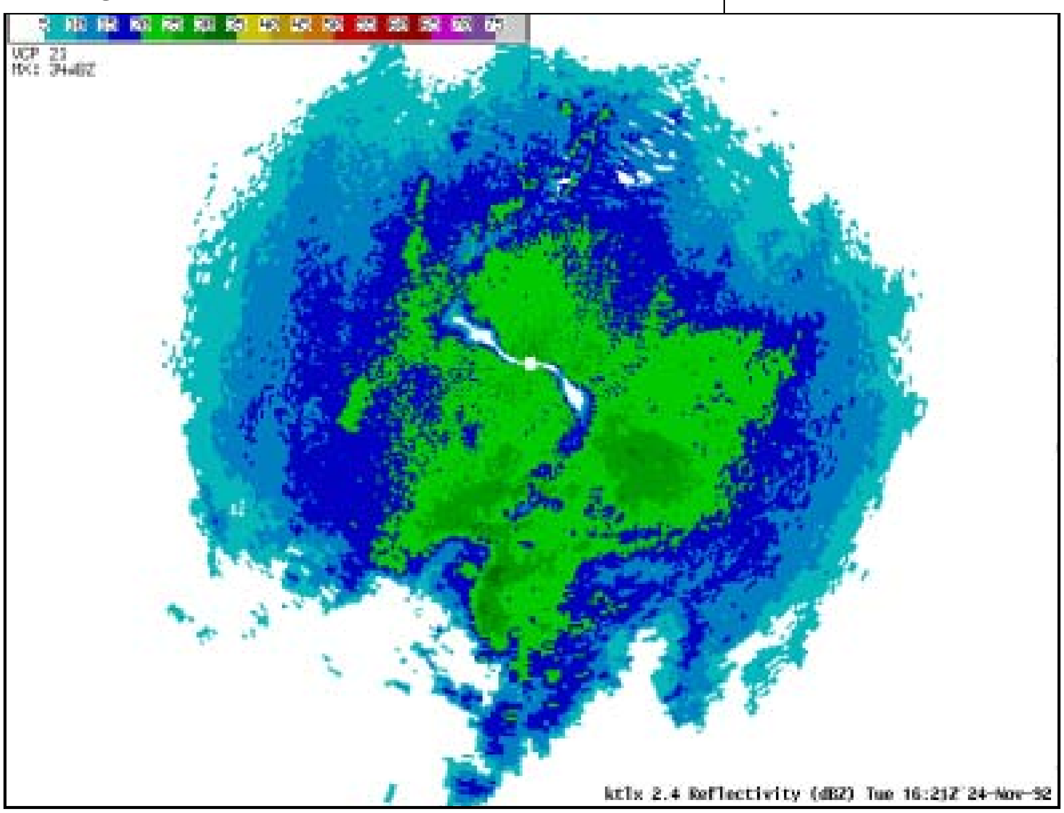


Figure 70. Example of Select Code All Bins inappropriately applied. Note the S shape reduction in reflectivity values near the RDA.

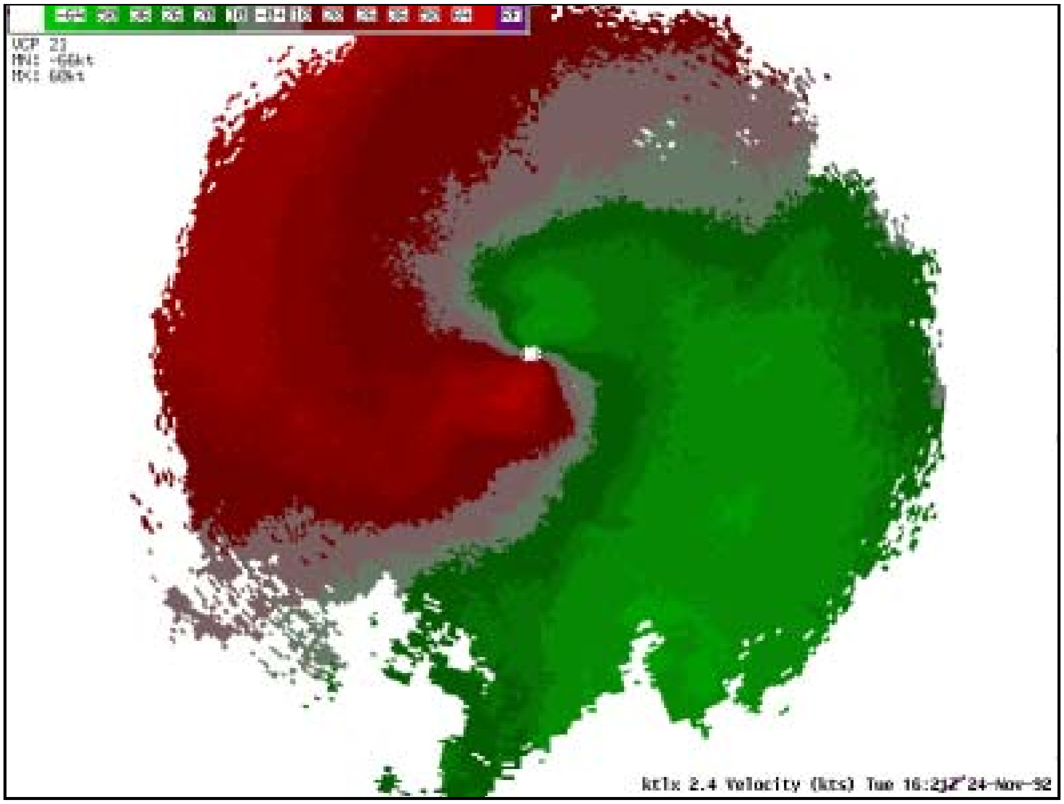


Figure 71. Example of Select Code All Bins inappropriately applied. Note the location of the zero isodop in the Base Velocity product relative to the location of reduced reflectivities in Figure 70.

Applying Select Code All Bins to the Batch Mode Elevations

The notch widths associated with the three levels of suppression on page 77 are the values for the lowest two elevations, 0.5° and 1.5°. These are the “Split Cut” angles, where the elevation is sampled once in CS mode and a second time in CD mode. For the middle elevations (2.4° through 6.2°) Batch mode is employed, where CS and CD are alternated through a single rotation. The notch widths are significantly wider in the Batch elevations, as much as ±15 kts. ***Applying Select Code All Bins for the Batch elevations can result in significant echo reduction. See Figure 72 and Figure 73.***

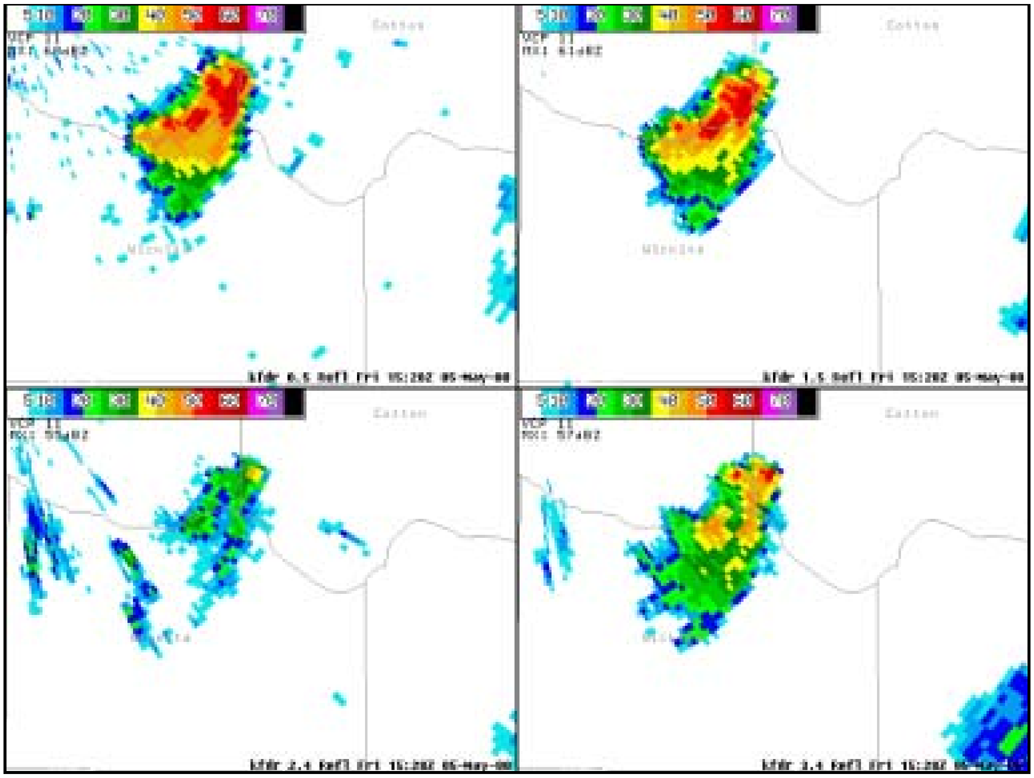


Figure 72. Example of Select Code All Bins inappropriately applied to the Batch elevations. Note the weak returns at the 2.4° and 3.4° elevations.

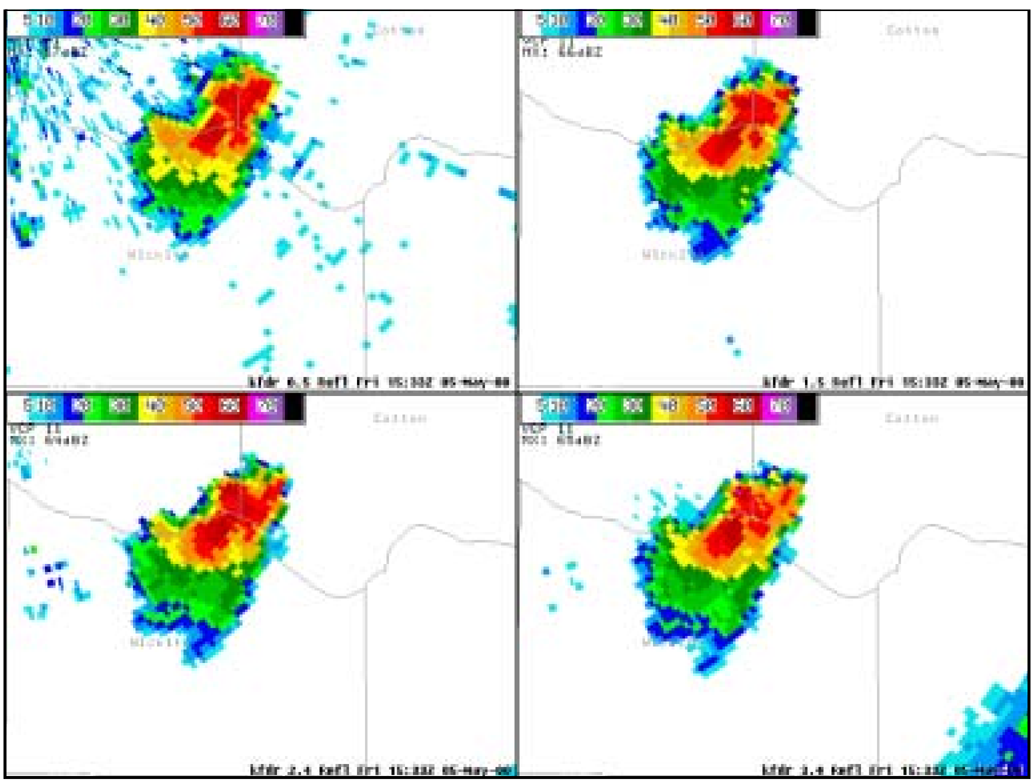


Figure 73. The inappropriate Select Code All Bins has been changed to Select Code Bypass Map. Note the significant improvement in returns at the 2.4° and 3.4° elevations.

Ground Clutter Suppression Limitations

For any given range bin, if the level of suppression is too low or too high, products generated from the base data will be affected. For Select Code All Bins improperly applied, large areas of base reflectivity values will be too low. Rainfall estimation is an example of one of the RPG algorithms that is greatly impacted by inappropriate clutter suppression.

Appropriate Ground Clutter Suppression Strengths

Improved Data Quality

Clutter suppression occurs ***before*** the base data are generated. Therefore the best quality products will result when the base data have been properly clutter filtered and are representative of the actual meteorological conditions.

Increased Velocity Data Beyond The First Trip

By reducing power returns from ground targets in the first trip, the likelihood of assigning valid velocity and spectrum width data to second trip range bins is increased.

Improved Ability to Stay in Clear Air Mode

The automatic switch from Clear Air to Precipitation mode occurs because a threshold of areal coverage of dBZs (above a certain minimum) has been exceeded. Applying appropriate clutter suppression will prevent non-meteorological returns from contributing to this areal coverage, preventing an inappropriate switch to Precipitation mode.

Fewer Velocity Dealiasing Failures in VCP 31

Unsuppressed ground clutter will bias mean radial velocity estimates. In VCP 31, a relatively low PRF is employed for velocity estimates, which results in a low V_{max} and frequent aliasing. The Velocity Dealiasing Algorithm will be most successful in dealiasing velocity estimates that are meteorologically plausible. Thus fewer failures will occur when the clutter bias is removed.

Suggested Clutter Regions File Management

It is recommended that each Clutter Regions file be designated for a specific clutter problem. The Baseline Set of files is designed to serve the function of having readily available, predefined files to address specific clutter problems.

For example, the Default file employs the Bypass Map for the entire radar coverage area and for all elevations angles. This file can be downloaded at any time that Bypass Map filtering to address normal clutter is needed. If your office has a geographic region where AP frequently occurs, another file could be set aside with the appropriate All Bins filtering within this region and the Bypass Map in control elsewhere. The download command is then all that is necessary to invoke clutter filtering to address the AP.

It is highly recommended that an office policy be implemented to document any changes made to clutter filtering during a shift. Recording the time, date, and filename any time a Clutter Suppression Regions file is downloaded will benefit operations during subsequent shifts. Also, the most recently downloaded file will be displayed when the Clutter Regions window is opened. This will allow for a quick check of the file currently in effect.

Range Folded Data

Range folding is the contemporary term for multiple trip echoes. The color purple on Velocity and Spectrum Width is often referred to as range folded data. However, the color purple results when echoes from different ranges are folded (i.e. overlaid) into the same ***apparent*** range. The process of assigning the color purple is presented in the "Range Unfolding Algorithm" section on page 98.

Often on Velocity and Spectrum Width products

To meet accuracy requirements for velocity estimates (a high V_{max}), high PRFs are employed. As a result, a R_{max} of 62 to 95 nm is typical, yet the maximum display range for the Mean Radial Velocity and Spectrum Width products is 124 nm. Thus, the velocity data will routinely have multiple trip echoes, requiring an algorithm to "unfold" them.

Purple (RF) assigned

In the case where multiple trip echoes are overlaid, the color purple will be assigned to one or both range bins corresponding to the original echo ranges. The purple color on Mean Radial Velocity and Spectrum Width products corresponds to the label "RF" on the data levels and is the result of the algorithm being unable to determine an accurate velocity estimate at that range. See Figure 74 and Figure 75.

Occasionally on Reflectivity products

Reflectivity data, with accurate range information, is obtained employing low PRFs. With the WSR-88D, for the lowest two elevation angles, where the problem of range folding is the greatest, the R_{max} is about 250 nm. Since this range is very near the maximum display range for Reflectivity products, second trip returns are possible.

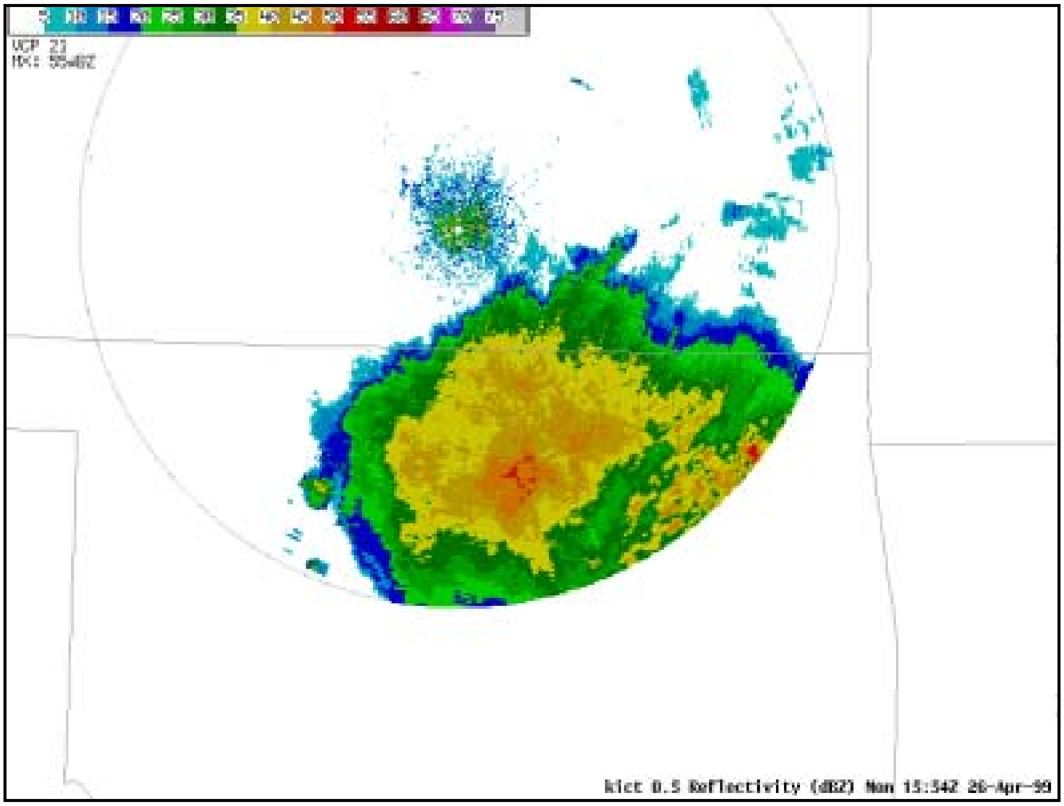


Figure 74. Range Folding example. Note the large area of strong echoes to the southeast of the RDA.

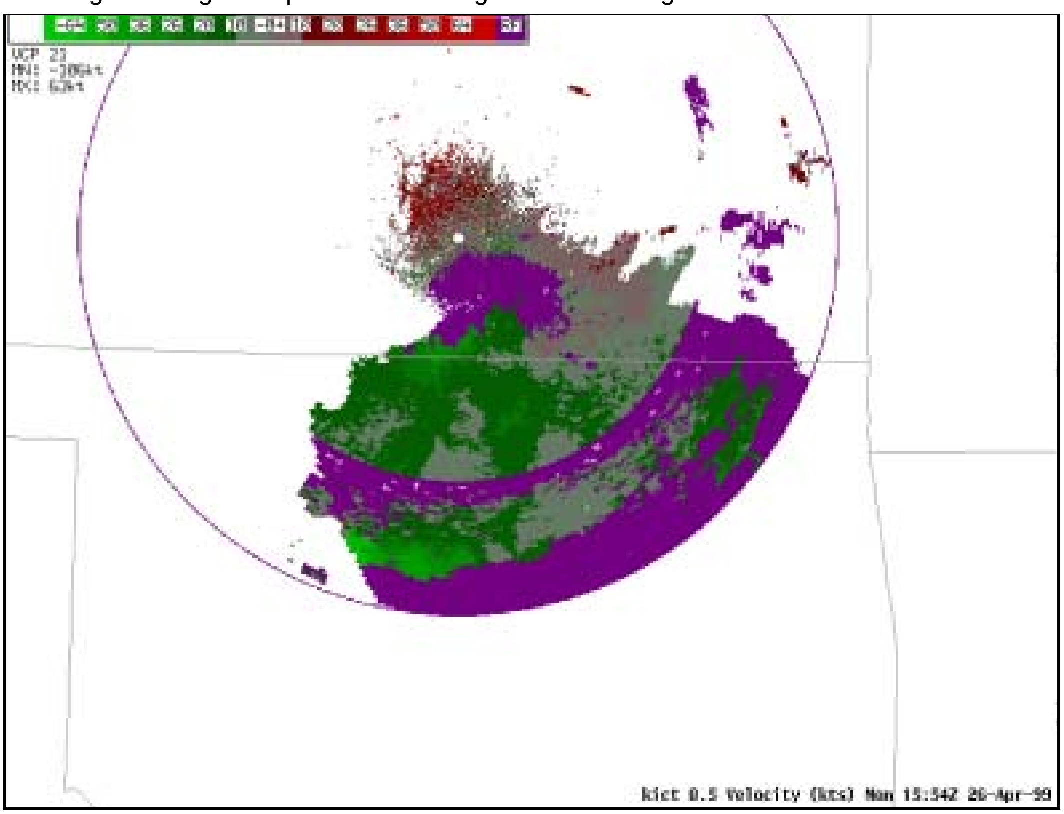


Figure 75. Base Velocity product associated with Figure 74. Note the wedge of purple close to the RDA. Velocity data has been assigned to the corresponding range gates in the second trip.

Elongated echoes

Range folded data on Reflectivity products will appear as elongated echoes, usually close to the radar.

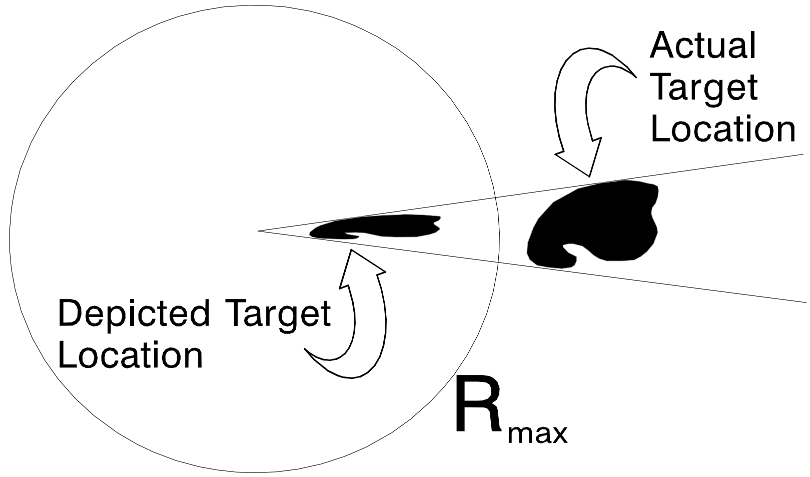


Figure 76. Schematic of the appearance of range folded data on a Base Reflectivity product. There is no purple, RF, assigned to Reflectivity products.

Color purple ***not*** assigned

Range folding ***can*** occur with the Reflectivity products, though it is uncommon. However, no Range Unfolding Algorithm is employed for Reflectivity products, and the color purple is ***not*** assigned as an indication of range folding.

Range Unfolding Algorithm

The Range Unfolding Algorithm is run at the RDA. It assigns the proper range to velocity and spectrum width data, which may be ***beyond*** the maximum unambiguous range. The Range Unfolding Algorithm is ***not*** employed for Reflectivity products.

Non-overlaid echoes case

This first case involves echoes positioned along a radial such that when the high PRF (CD) is employed and R_{max} is short, there are no echoes occupying the same apparent range in the first trip.

Step 1: True range and possible ranges

After the low PRF (CS) data have been collected, each target's range and returned power is known.

However, the velocity estimates are quite poor and are ***not*** used. See Figure 77.

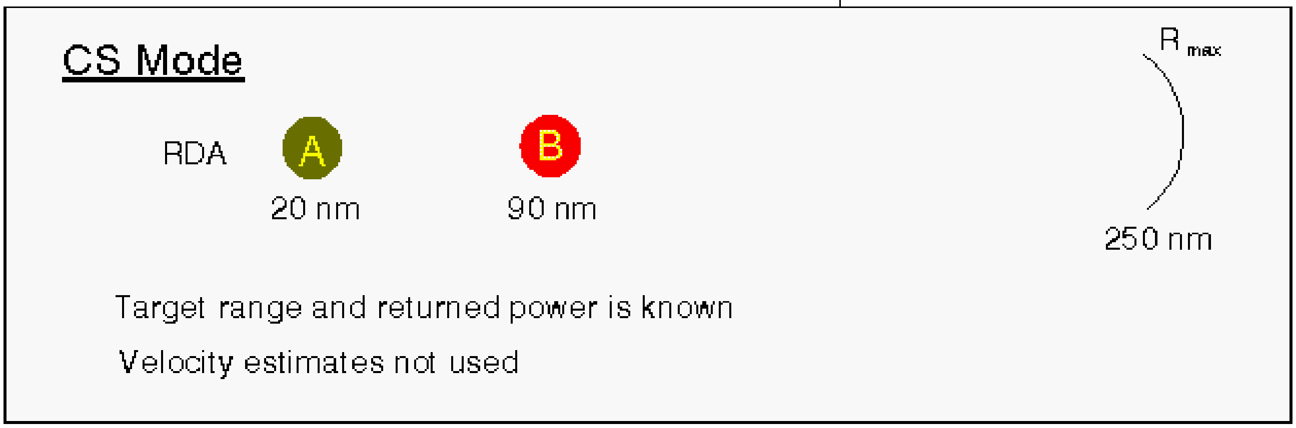


Figure 77. Looking along a radial, note the range of each target when the Surveillance PRF is employed.

For a given radial, the algorithm computes the ***apparent range*** that each target will have when the high PRF (CD) mode is employed. The apparent range will be within the first trip. See Figure 78.

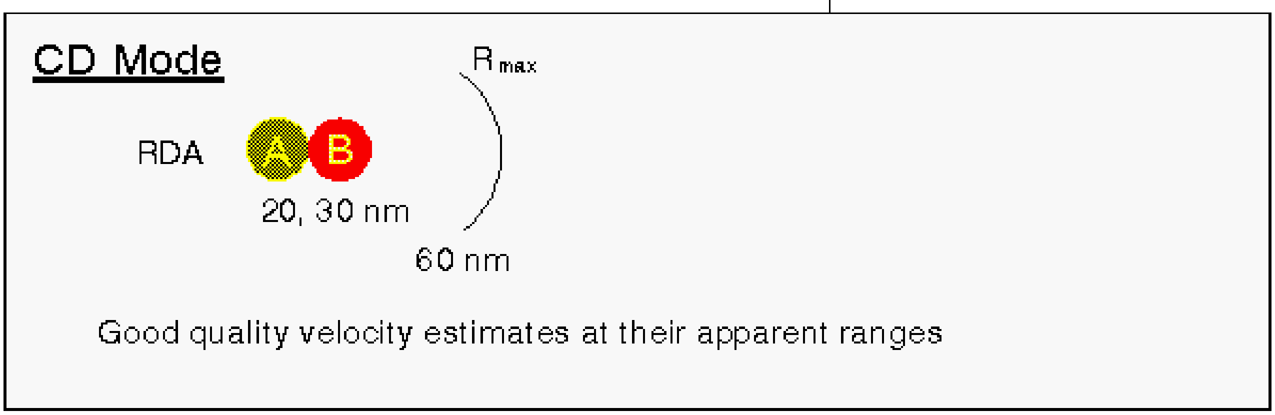


Figure 78. The computed ***apparent*** ranges in Doppler mode of each target. The ranges are calculated prior to collecting the Doppler data.

The algorithm also computes ***all possible ranges*** within subsequent trips for each target. Therefore, when the Doppler data are collected (employing high PRFs), all possible target ranges will have been previously identified. See Figure 79.

Step 2: Power comparison

The algorithm determines if there will be any echoes “folded” into the same range bin when the CD waveform is employed. If so, the power returns of

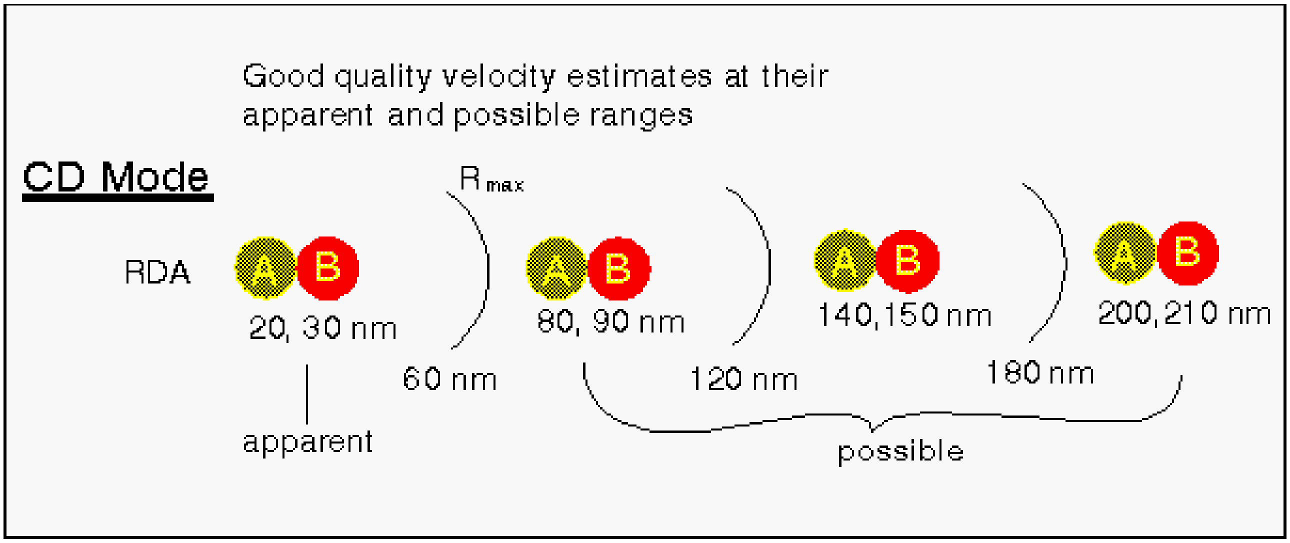


Figure 79. The ***apparent and possible*** ranges in Doppler mode of each target. The ranges are determined prior to collecting the Doppler data.

the two or more echoes are compared. In this case, there are no echoes folded into the same bin, hence no echo overlay.

Step 3: Unfolding

The high PRF (CD) data are collected. The velocity and spectrum width data will be accurate but, due to the short R_{max}, any echoes beyond R_{max} will be ***folded*** into the first trip. The unfolding step involves checking the CS data (power and range) bin by bin against the CD data (velocity and spectrum width values). The apparent range of a velocity value in the CD data is verified by checking that range in the CS data. See Figure 80.

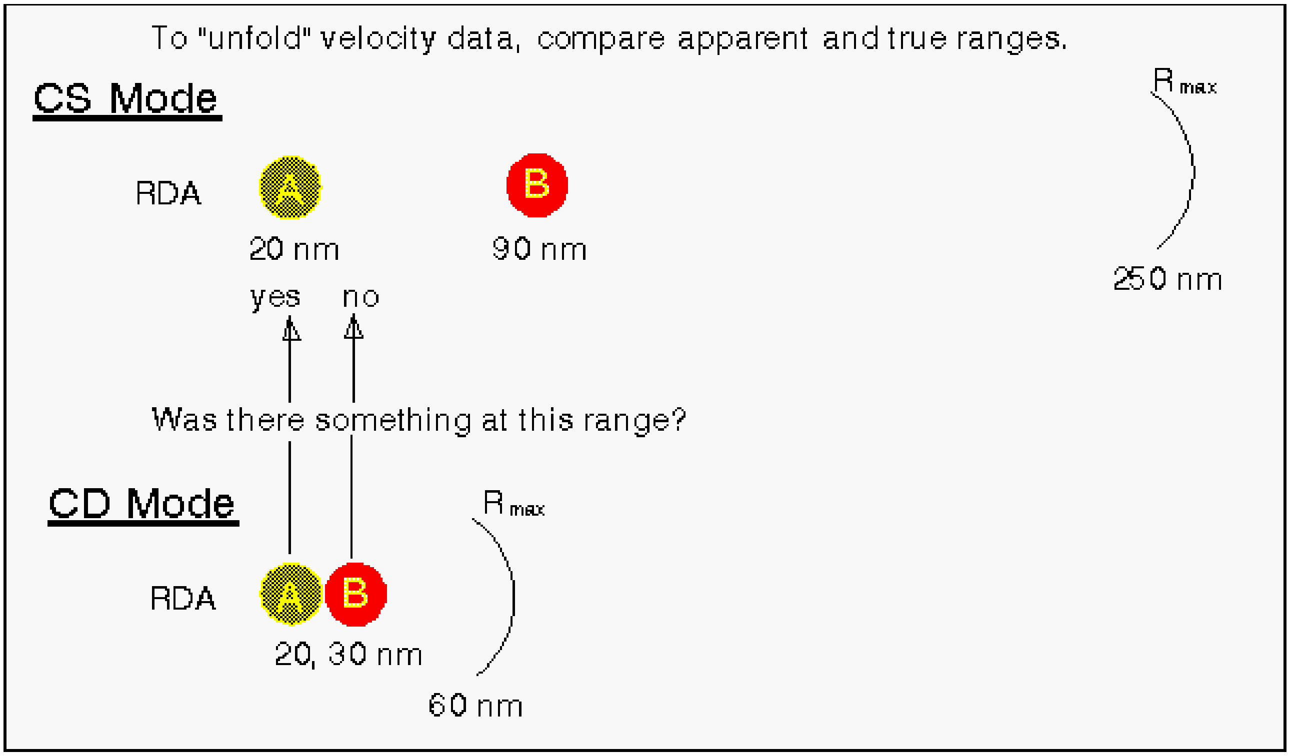


Figure 80. The apparent range of a velocity value in the CD data is compared to that range in the CS data.

If there were no target in the CS data at the apparent range, the possible range(s) are then compared to the CS data (see echo B, Figure 81). If there was an echo in the CS data at a possible range, then the velocity will be assigned at that range.

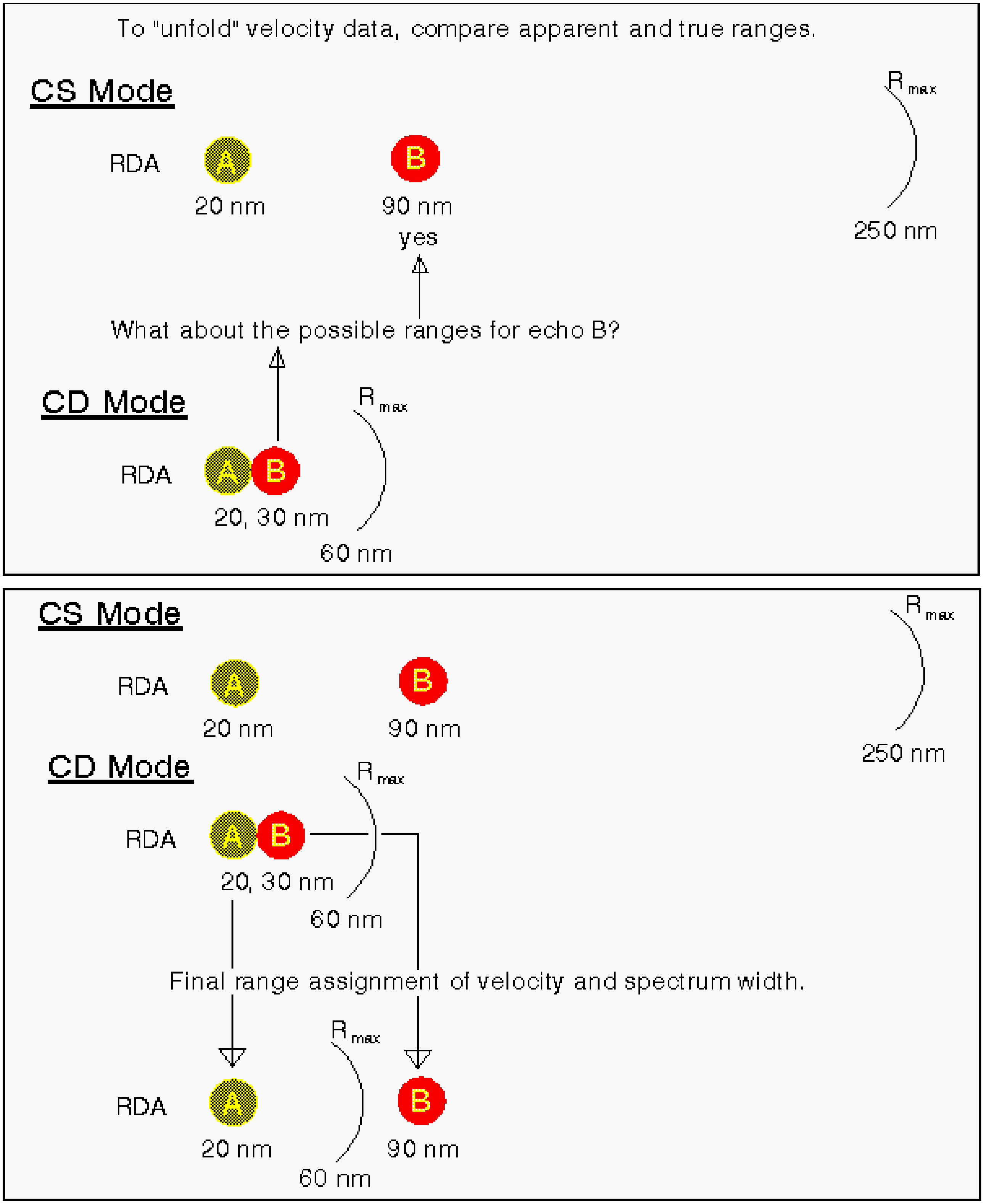


Figure 81. The range assignment of velocity data, Base Velocity and Base Spectrum Width.

Overlaid echoes case

In this case, the echo positions along the radial are such that in CD mode there ***will*** be echoes folded into the same range bin. For echoes A and B, when the CD R_{max} = 70 nm, the true ranges of 20 nm and 90 nm would ***both*** have apparent ranges of 20 nm. Thus the velocity value that appears to be at a range of 20 nm is actually a blend of the two original targets. Since velocity estimates are power weighted, velocity data associated with an overlaid echo will be representative of one of the two (or more) echoes ***only if*** one of them has returned significantly greater power than the other(s).

Step 1: True range and possible ranges

As in the previous case, once the CS data have been collected, power and range information for each target along a radial is known. See Figure 82.

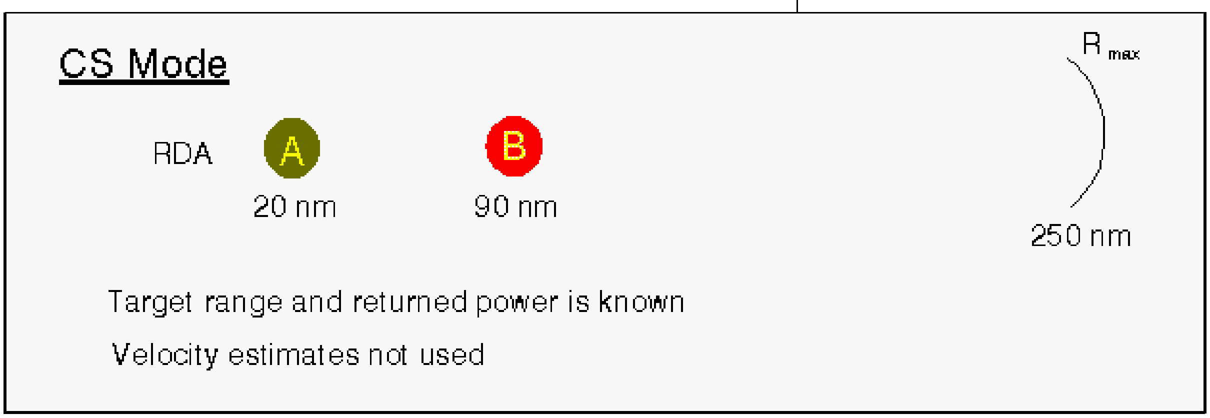


Figure 82. Looking along a radial, note the range of each target when the Surveillance PRF is employed

For a given radial, the algorithm computes the ***apparent range*** that each target will have when the high PRF (CD) mode is employed. This apparent range will be within the first trip. See Figure 83.

The algorithm also computes other possible ranges within subsequent trips for each target. Therefore, when the Doppler data are collected (employing high PRFs), all possible target ranges

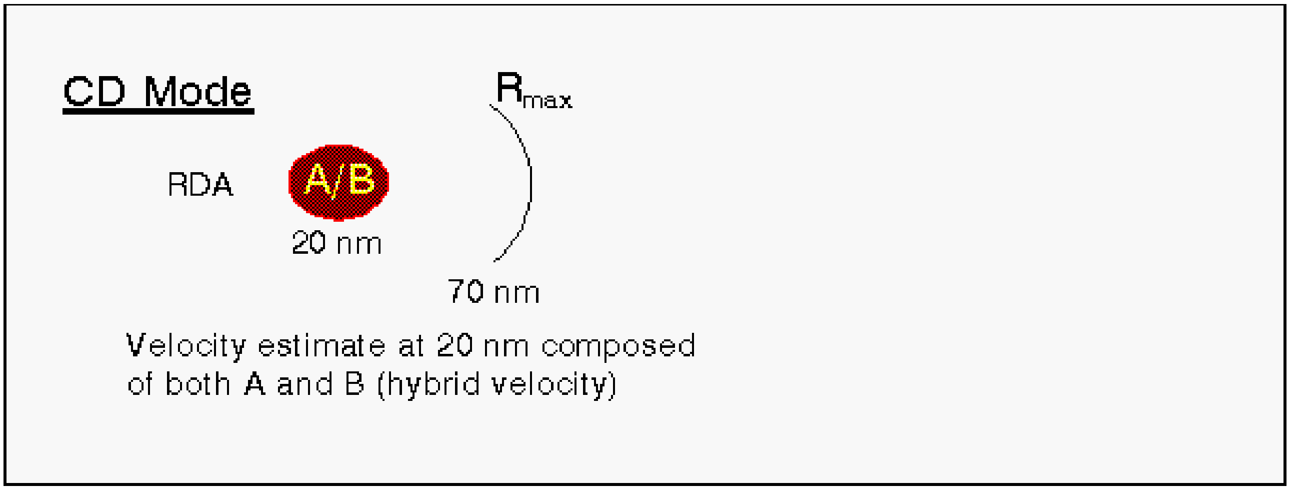


Figure 83. The computed apparent ranges in Doppler mode. The ranges are calculated prior to collecting the Doppler data. Note that echoes A and B will be overlaid.

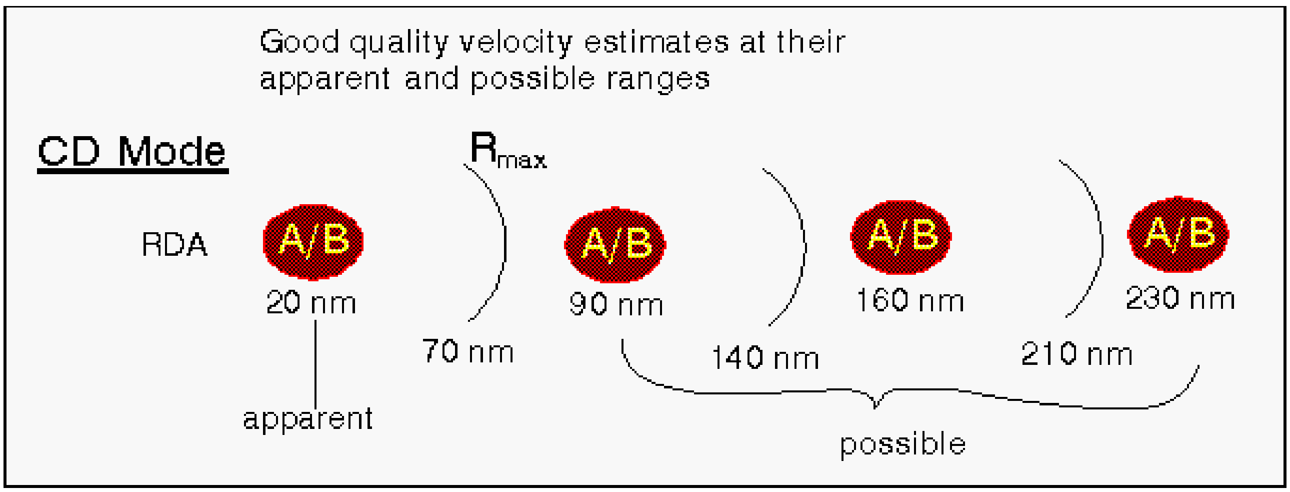


Figure 84. The apparent and possible ranges in Doppler mode of each target. The ranges are determined prior to collecting the Doppler data. Note the repeated echo overlay.

will have been previously identified. See Figure 84.

Note that when the velocity data are collected, the velocity and spectrum width estimates that are at an apparent range of 20 nm will be a ***hybrid*** of the returns from ***both*** targets A and B.

Note in Figure 85 that the hybrid velocity estimate is more representative of B than A. Target B has returned higher power than target A. Since velocity estimates are power weighted, assigning a hybrid

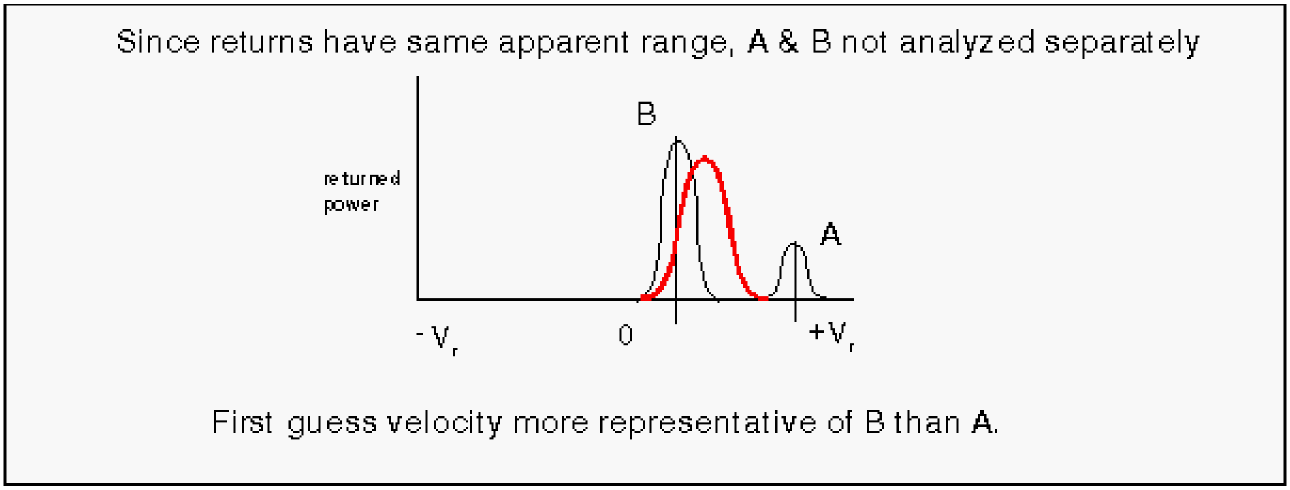


Figure 85. Since the signals from both targets A and B return to the RDA at the same time, they are analyzed as a single target.

velocity estimate to a target that has returned significantly greater power than the other(s) will result in a reasonably accurate estimate.

Step 2: Power comparisons

From the CS data, the returned power of the two echoes is known. The power ratio (higher to lower) in dB is computed.

$$dB = 10\log\left(\frac{P_{high}}{P_{low}}\right)$$

- If the power ratio exceeds TOVER (an adaptable parameter with a default value of 5 dB), then velocity and spectrum width data will be assigned to the echo returning the highest power, while the other(s) will be assigned the color purple.
- If the power ratio does not exceed TOVER, ***all*** overlaid echoes will be assigned the color purple.

Step 3: Unfolding

The high PRF (CD) Doppler data are collected. As before, the apparent and possible ranges of a velocity value in the CD data (velocity and spectrum width) are compared to the true range in the CS data (power and range).

For this example, assume the power ratio of echo B over echo A exceeds TOVER. Since the range of both echoes is known, velocity data will be assigned to echo B at 90 nm, with RF, purple, assigned to echo A at 20 nm. Note that the velocity data assigned to the range of echo B is slightly biased by the returns from echo A.

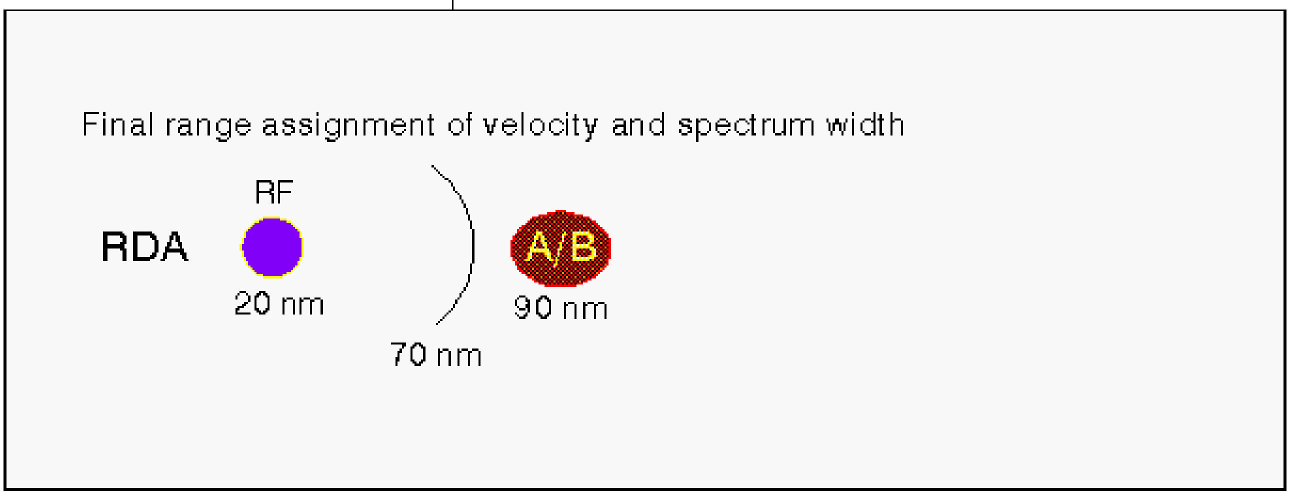


Figure 86. For the range bins where echo overlay has occurred, the assignment of velocity data or purple (RF) is determined by the power ratio and TOVER.

The Effects of TOVER

Higher TOVER values

Higher TOVER values (for example, 10 dB rather than 5 dB) ***improve the accuracy*** of the velocity and spectrum width data that are assigned. Any velocity estimate that is assigned to an echo would have minimal bias by the other echoes.

However, higher TOVER values also result in ***larger areas of range folded (RF) data***. A higher TOVER is a condition harder to meet for the assignment of velocity and spectrum width data, resulting in more cases where all overlaid echoes are colored purple (RF).

Lower TOVER values

Lower TOVER values (for example, 5 dB rather than 10 dB) result in ***significantly less range folded (RF) data***. The lower TOVER is an easier condition to meet, and thus more echoes will be assigned velocity and spectrum width data.

However, the estimates of velocity and spectrum width data will be ***slightly biased***. For a TOVER set at 5 dB, any velocity estimate that is assigned to an echo would be more biased by the other(s) than if a velocity estimate was assigned for a TOVER set at 10 dB.

Range Unfolding Algorithm

Strengths

Velocity and Spectrum Width beyond the first trip

The Range Unfolding Algorithm assigns the proper range to velocity and spectrum width data, which may be beyond the unambiguous range of the Doppler (CD) PRF. When there is echo overlay, one of the overlaid returns will be assigned velocity and spectrum width data if their power ratio exceeds TOVER, while the other(s) will be assigned purple (RF).

Mitigating the Doppler Dilemma

Employing the Range Unfolding Algorithm allows the use of a low PRF mode to properly determine target range and a high PRF mode to accurately measure velocity and spectrum width data.

Limitations

Squall lines over the RDA

Certain meteorological conditions will be more conducive to range folding than others. Any event that results in numerous echoes being aligned along a radial will ***maximize*** echo overlay in Doppler mode, and thus range folded (RF) data will also be maximized.

Velocity and spectrum width may be unavailable

When echoes are overlaid, velocity and spectrum width data are unavailable if their power ratio does not exceed TOVER. The echoes will be assigned purple (range obscured).

TOVER changed at RDA site

TOVER cannot be changed “on the fly”. It is an RDA adaptable parameter, and can only be changed at the RDA site, usually by maintenance personnel.

Improperly Dealiased Velocities

Pulse-to-pulse phase shifts

Recall that mean radial velocity is computed from a series of phase shifts measured from one pulse to the next.

True pulse pair phase shift less than 180°

Velocity detection is unambiguous, as long as the true pulse pair phase shift is <180°. The WSR-88D's first guess velocity is based on an assumed phase shift of less than 180°.

True pulse pair phase shift equals or exceeds 180°

If the true pulse pair phase shift ≥180°, the radar's first guess will be wrong (by a predictable amount), and the velocity will be aliased.

Improperly dealiased velocities, not properly resolved by the Velocity Dealiasing Algorithm, will show up primarily in two ways:

Isolated range gates

1. Isolated range gates will have velocity values in the opposite direction than the surrounding data. This occurs primarily near the radar in the ground clutter pattern.

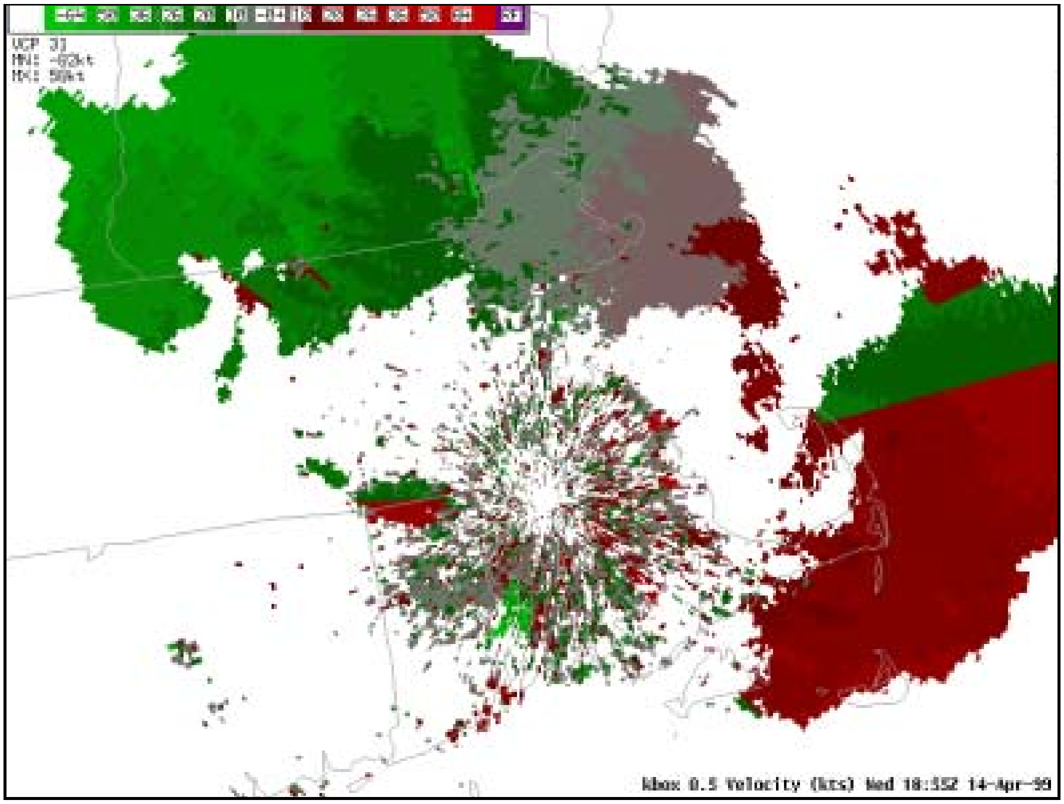


Figure 87. Isolated range gates of improperly dealiased velocities at close range to the RDA.

2. These are blocks of velocities with values in the opposite direction from the surrounding data, or to wind information obtained from other sources (such as upper air charts or soundings). There will be no zero velocities to separate the two fields, and it is common to see shears which are not meteorologically realistic. See Figure 88 - Figure 91.

"Spikes" or "wedge shaped blocks"

Recall that aliased velocities (incorrect first guess velocity) will occur where winds exceed V_{max}. The Velocity Dealiasing Algorithm will be most successful in areas of continuous data, thus improperly dealiased velocities are most likely in areas lacking continuous, or surrounding velocities.

Most likely in areas lacking continuity

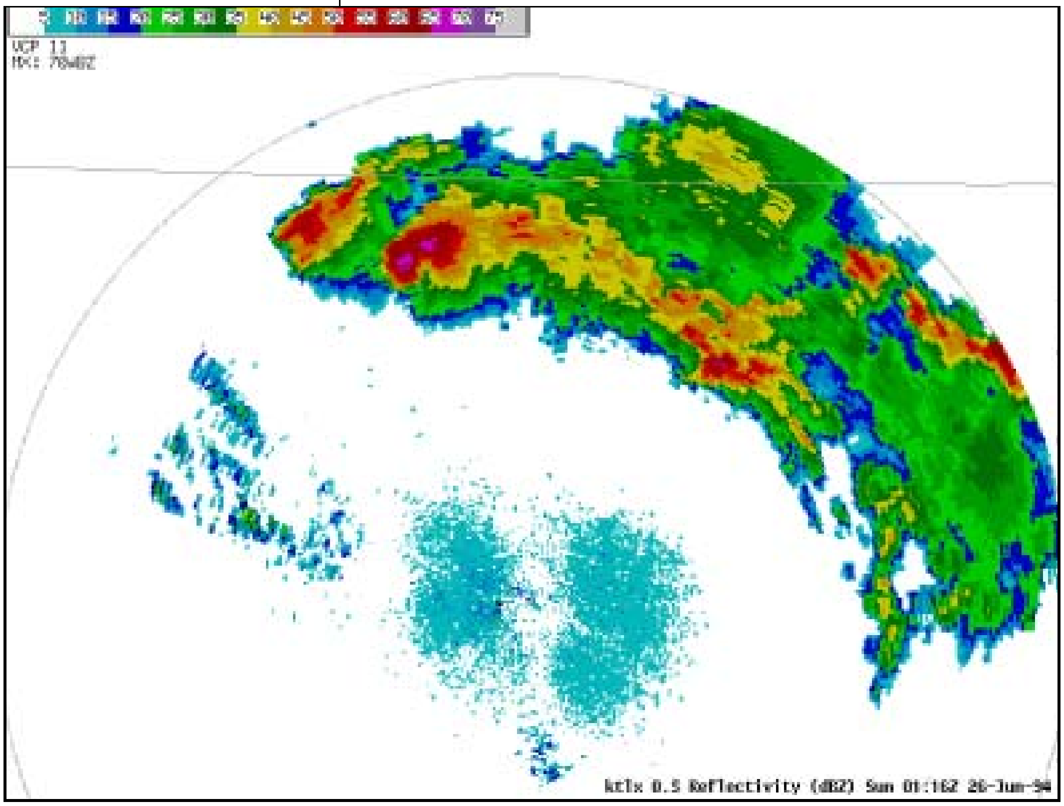


Figure 88. Base Reflectivity product associated with Figure 89.

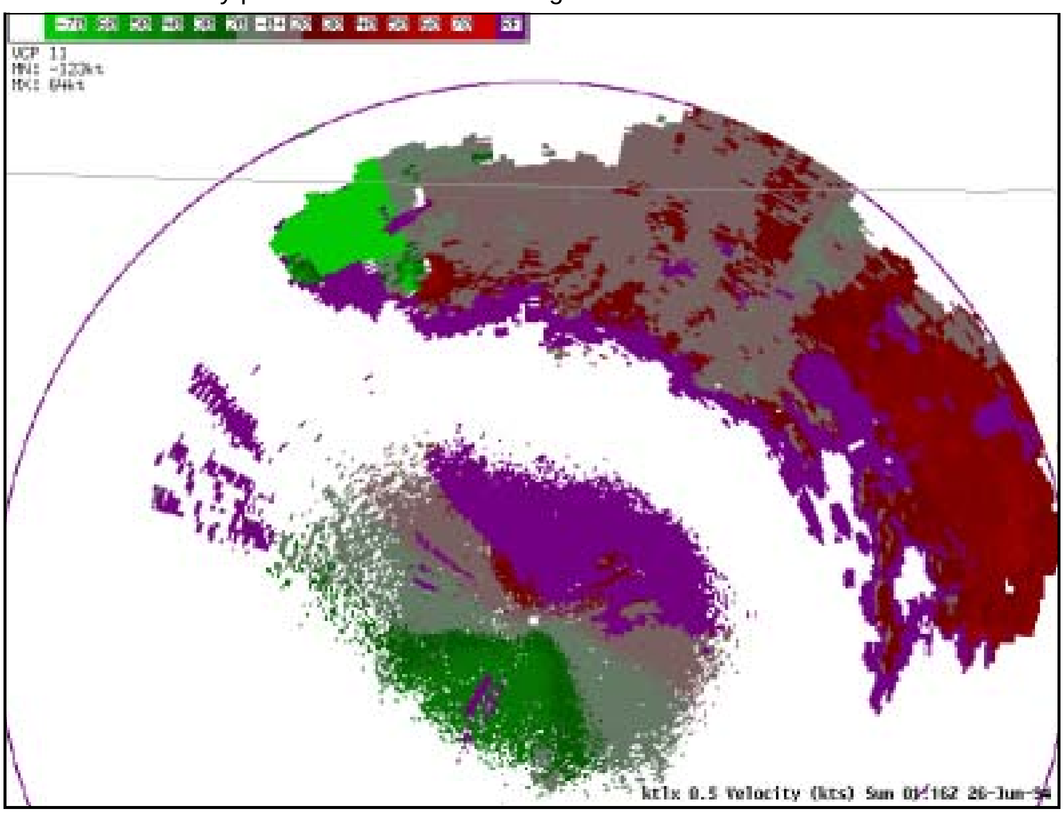


Figure 89. Base Velocity product with improperly dealiased velocities. Note the area of maximum inbound velocities to the north-northwest of the RDA.

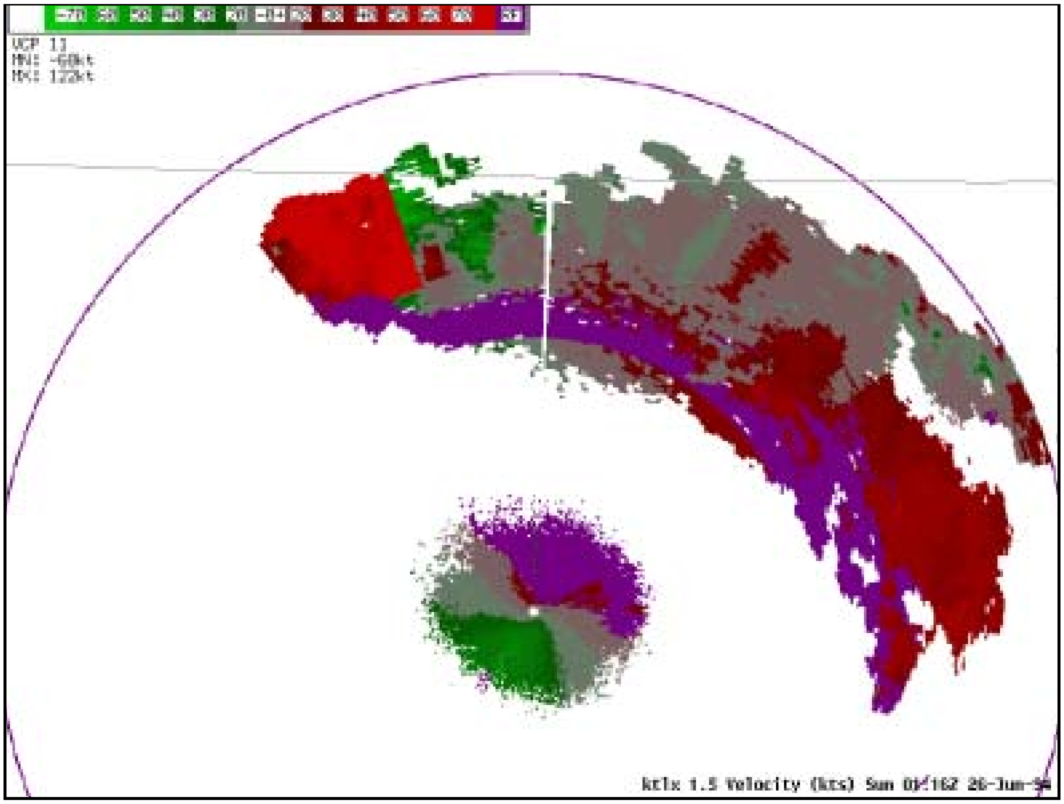


Figure 90. Base Velocity (1.5°) with improperly dealiased velocities. Note the block of maximum outbound velocities to the north-northwest of the RDA.

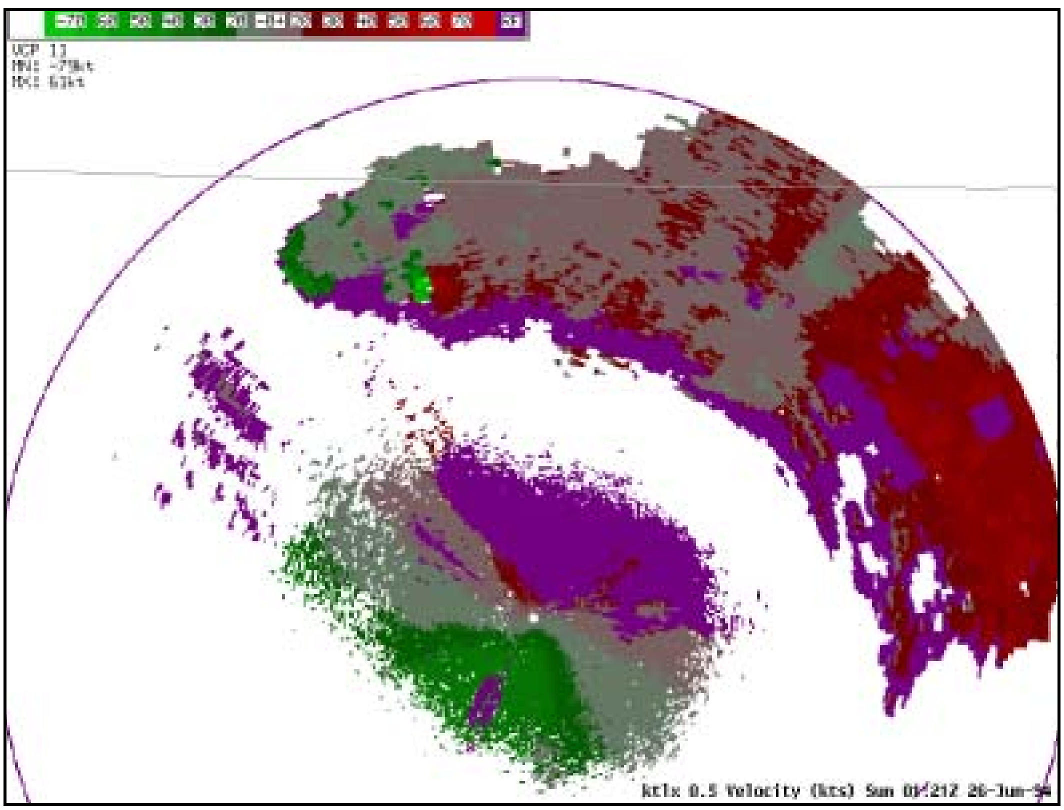


Figure 91. Base Velocity product from the next volume scan. The Velocity Dealiasing Algorithm was successful for this volume scan.

Velocity Dealiasing Algorithm

Once the reflectivity, velocity and spectrum width base data are transmitted from the RDA to the RPG, the Velocity Dealiasing Algorithm is executed. Adaptable parameter settings for this algorithm vary dependent on whether long or short pulse is employed. The long pulse settings are an attempt to mitigate velocity dealiasing failures in VCP 31.

Identify and correct aliased velocities

The velocity data have been appropriately placed with respect to range by the Range Unfolding Algorithm. Now, aliased velocities will be identified and corrected. The Velocity Dealiasing Algorithm essentially compares each first guess velocity value to its neighbors.

Primarily based on continuity

If a velocity varies significantly from its neighbors, the algorithm attempts to substitute an alias of that velocity. Recall that the PRF and thus V_{max} is known, and computing aliases for any first guess velocity is straightforward. Since the algorithm depends on surrounding data, it is primarily based on continuity.

Preserves meteorological features

The Velocity Dealiasing Algorithm is also designed ***specifically*** to preserve meteorological features such as mesocyclones, storm top divergence, etc. It is structured such that the minimum amount of computer time necessary is used and is thus well suited to operational constraints.

Step 1: Radial Continuity Check

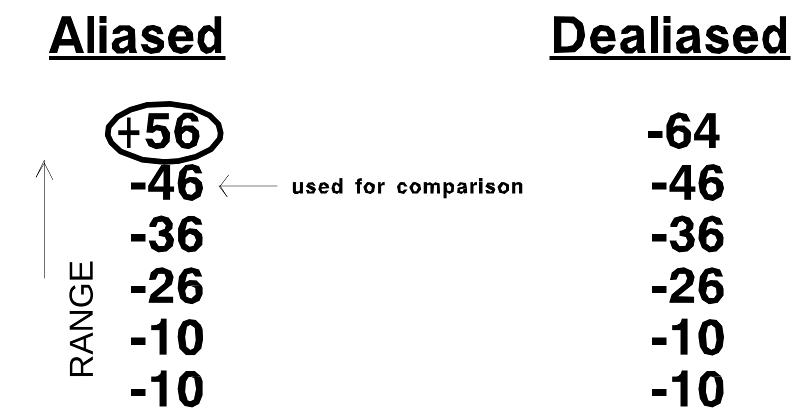


Figure 92. The closest (within 5 bins) velocity value along the radial (searching toward the radar) is used for comparison. In this example, V_{max} = 60 knots.

Closest valid velocity neighbor found

The first guess velocity for a range bin is compared with the ***closest*** valid velocity (within 5 range bins) along the same radial, searching back ***toward*** the radar. Thus, the comparison value will be a velocity that has ***already*** been processed by the algorithm.

First guess and aliases compared

The first guess velocity is compared to this neighbor. If the first guess is not within a threshold of this neighbor, then its aliases are checked. If one of them is within the threshold, it is retained. Error checks are then made and the algorithm moves on to the next range bin.

How the Radial Continuity Check might fail

If the first guess velocity and its aliases (the few that are meteorologically possible) ***all*** fail to fall within the threshold value of the closest neighbor, then the algorithm moves on to step 2. Also, if there are no valid velocities within 5 range bins of the first guess velocity, then step 2 is necessary.

Step 2: Nine Point Average

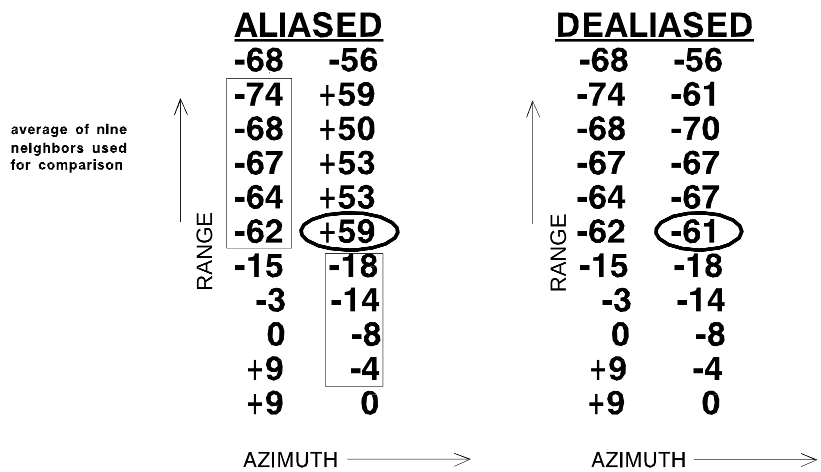


Figure 93. The average of nine neighboring velocity values is used for comparison. In this example, the average is -42 and V_{max} = 60 knots.

Average is computed

Here, an average velocity is computed using four values in the same radial (closer to the radar) and five values in the adjacent preceding radial (adjacent point and four further from the radar). In Figure 93, the Nine Point Average is -42.

First guess and aliases compared

The first guess velocity is then compared to this average. If the first guess is not within a threshold of this average, then its aliases are checked. If one of them is within the threshold, it is retained. Error checks are made and the algorithm returns to step 1 on the next range bin.

How the Nine Point Average might fail

If the first guess and its aliases ***all*** fail to fall within a threshold of the average, then the first guess is removed from that bin and No Data (ND) is assigned. If an average velocity is not obtainable, the algorithm proceeds to step 3.

Step 3: Expanded Search

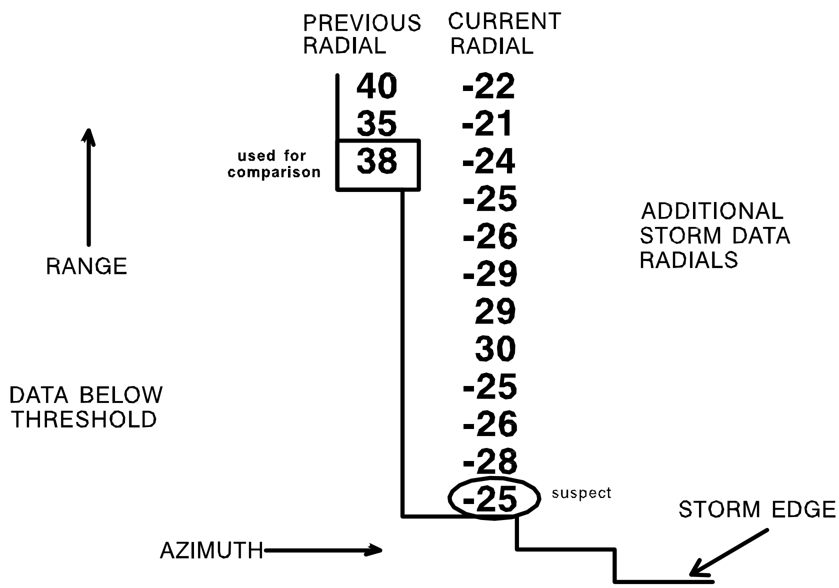


Figure 94. A search for a neighboring velocity for comparison: up to 30 gates along the radial toward the radar or up to 15 gates along the preceding radial away from the radar.

Searching for valid velocity neighbor

Searching for a neighboring velocity value, the algorithm looks back along the radial (toward the radar) up to 30 bins and forward along the preceding radial (away from the radar) up to 15 bins.

First guess and aliases compared

The first guess velocity is compared to this neighbor. If the first guess is not within a threshold of this neighbor, then its aliases are checked. If one of them is within the threshold, it is retained. Error checks are made, and the algorithm returns to step 1 on the next range bin.

How the Expanded Search might fail

If a velocity neighbor is found but the first guess and its aliases ***all*** fail to fall within a threshold of this neighbor, or if a valid neighboring velocity cannot be found, the algorithm proceeds to step 4.

Step 4: Environmental Winds

The final step for the Velocity Dealiasing Algorithm is accessing the Environmental Winds Table (EWT). This table contains mean winds beginning at the surface and at 1000 ft intervals up to 70k ft. The EWT is presented as part of the Environmental Data Editor window (Figure 95). Selecting the Data Entry button on the Environmental Data Editor window will open the Environmental Data Entry window. In this window, the EWT values are also presented in a tabular format (Figure 96).

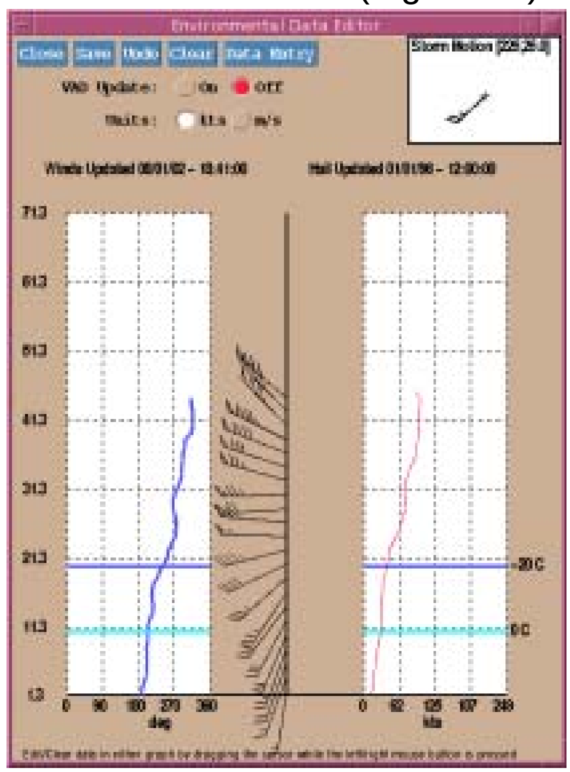


Figure 95. Environmental Data Editor window .

First guess and aliases compared

If the first three steps fail to find a valid neighboring velocity for comparison, the first guess velocity is compared to a velocity obtained from the Environmental Winds Table. If the first guess is not within a threshold of the Environmental Winds Table value, then its aliases are checked and, if one of them is within the threshold, it is retained. If the first guess and its aliases ***all*** fail to fall within a threshold of the Environmental Winds Table value,

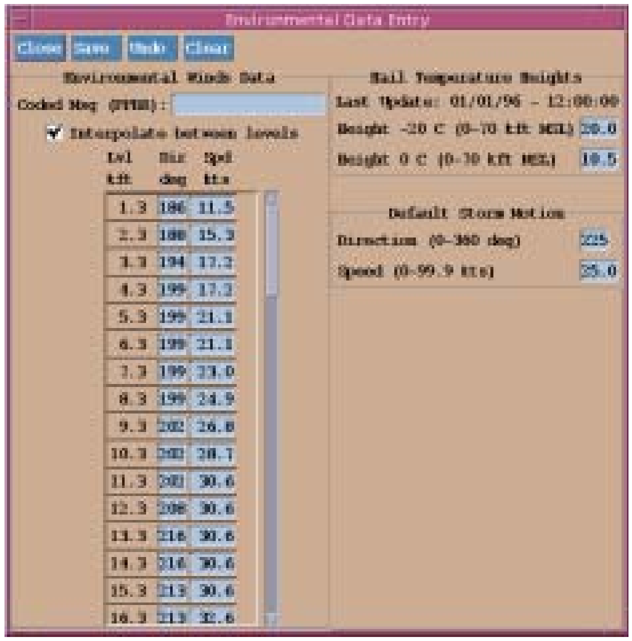


Figure 96. Environmental Data Entry window.

then the first guess is removed and No Data (ND) is assigned.

Importance of a current Environmental Winds Table (EWT)

Unless the operator specifies otherwise, the EWT will be automatically updated by the output of the Velocity Azimuth Display (VAD) algorithm. Since the EWT is usually updated automatically using VAD estimated winds, improperly dealiased velocities can be placed in the table, and then in turn be used to dealias future products! A check of the EWT against radiosonde data each 12 hours is a good way to ensure that the table is current. Any time that improperly dealiased velocities become excessive, checking the EWT is recommended.

Error Checks

Error checks are made throughout the execution of the Velocity Dealiasing Algorithm. If an ***aliased*** velocity is used as a valid neighbor, without checks, the aliasing can propagate for numerous radials and azimuths. The error checks are designed to prevent the radial spread of aliased velocities.

Velocity Dealiasing Algorithm

Strengths

Best possible velocity data for downstream algorithms

The Velocity Dealiasing Algorithm provides the ***best possible*** base velocity data for the Base and Derived products, and downstream algorithms. Of particular importance are the mesocyclone and TVS algorithms, which require dealiased data.

Accurate velocity estimates in excess of V_{max}

Without the Velocity Dealiasing Algorithm, identification of velocities greater than V_{max} would not occur.

Preserves significant meteorological features

The algorithm is ***specifically*** designed to ***preserve*** significant features such as gust fronts, storm-top-divergence, mesocyclones, and TVS.

Limitations

Improper velocity dealiasing can mask important features

Improper dealiasing ***can*** sometimes obscure or mask important meteorological signatures, making product interpretation difficult.

Algorithm performance sometimes degraded

There are several factors which can degrade the quality of velocity estimates and, therefore, algorithm performance. They include clutter contamination, high spectrum width, and a low SNR (returned signal power close to internal noise level).

Downstream meteorological algorithms sometimes contaminated

Improperly dealiased velocities will contaminate other algorithms, such as the detection of a false mesocyclone. False alerts may be triggered, requiring careful interpretation and investigation by operators.

Operational Considerations

Improperly dealiased velocities will ***rarely*** be preserved from one elevation angle to the next. For areas of questionable velocity values, check the same product at a higher or lower elevation angle, or examine the same product from a different volume scan by stepping forward or back. Also, note the environmental flow around the suspected area. For example, if the flow should be strongly toward the radar based on synoptic data, then large blocks of outbound velocities in that area would be improperly dealiased.

VCP 31 experiences more dealiasing errors

VCP 31 (long pulse), employs relatively low PRFs (compared to other VCPs) for velocity data collection. If aliasing is a problem, switch to VCP 32.

Minimizing Aliasing and Range Folding (Objective 4)

Minimizing Velocity Aliasing

The extent of aliasing (the number of first guess velocities that the Velocity Dealiasing Algorithm will attempt to dealias) is dependent on which VCP is being employed. The adaptable parameters for the Velocity Dealiasing Algorithm have different settings in long pulse (VCP 31) than in short pulse (VCPs 11, 21, and 32). This is to try to mitigate dealiasing failures in VCP 31.

Environmental Winds Table

Keeping the Environmental Winds Table updated will give the best results from the Velocity Dealiasing Algorithm.

Change PRFs

Clear Air Mode

If in VCP 31, a relatively low Doppler PRF is employed, resulting in a V_{max} of about 22 kts. For better velocity estimates, change to VCP 32, which employs a higher Doppler PRF such that V_{max} is about 51 kts.

Precipitation Mode

To increase V_{max}, the PRF can be increased manually. However, this will almost certainly increase the amount of range obscured (purple) data.

Minimizing Range Folding

The areal extent of range obscured data (the assignment of purple on Velocity and Spectrum Width products), can be controlled automatically or manually.

Auto PRF

The Auto PRF function is designed to minimize total range-folded obscurations every volume scan.

Minimizing overall range folding

Normally, Auto PRF should be kept on the majority of the time. Auto PRF analyzes echo returns using the lowest elevation angle in CS mode. The Doppler PRF that would yield the smallest ***overall*** obscuration is determined and used for all elevation scans <7.0° the next volume scan. Auto PRF will select one of the last ***four*** Doppler PRFs (#5, 6, 7, and 8).

Minimizing range folding for a storm of interest

Manual PRF selection

A manual PRF change is needed when an important storm is obscured by range folding. Any of the ***five*** Doppler PRFs (#4, 5, 6, 7, and 8) assigned to the WSR-88D can be manually selected. Auto PRF must first be set to off, ***then*** a CD PRF is selected manually. PRF selection is done at the PRF Selection window (See Figure 97).

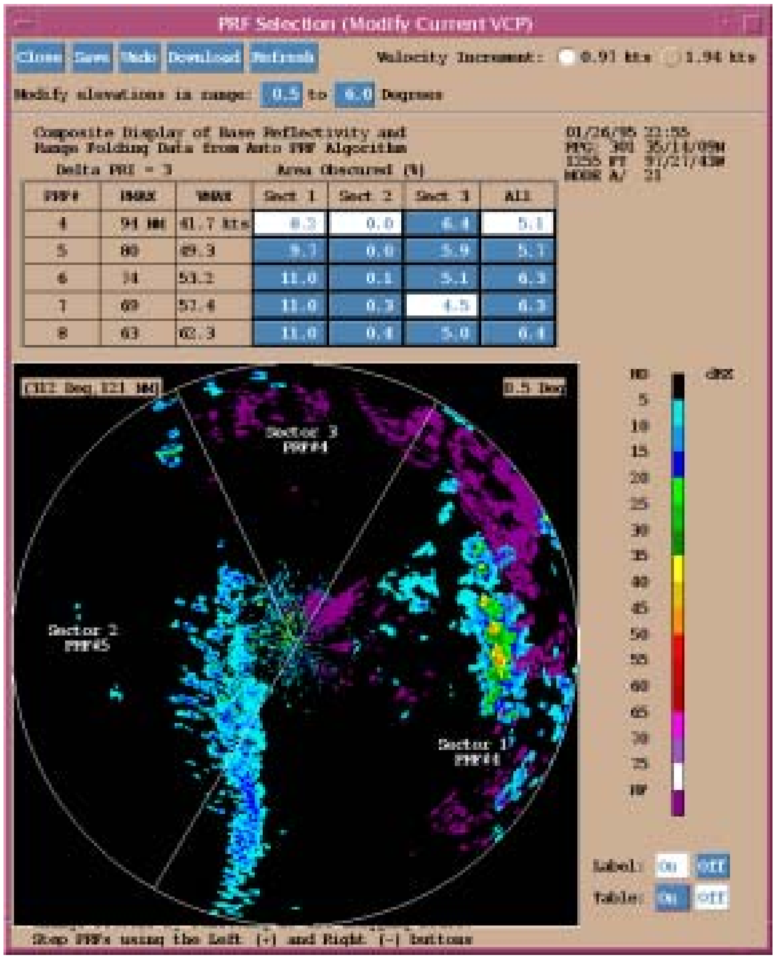


Figure 97. PRF Selection window at the RPG HCI.

In the Reflectivity data, (Figure 98), there is a Bounded Weak Echo Region (BWER) at 2.4°. This implies that the storm is rotating, thus investigation using the velocity data is imperative. However, the storm is obscured by range folding (Figure 99). Auto PRF is on, which will minimize range folding overall, but not for this particular storm.

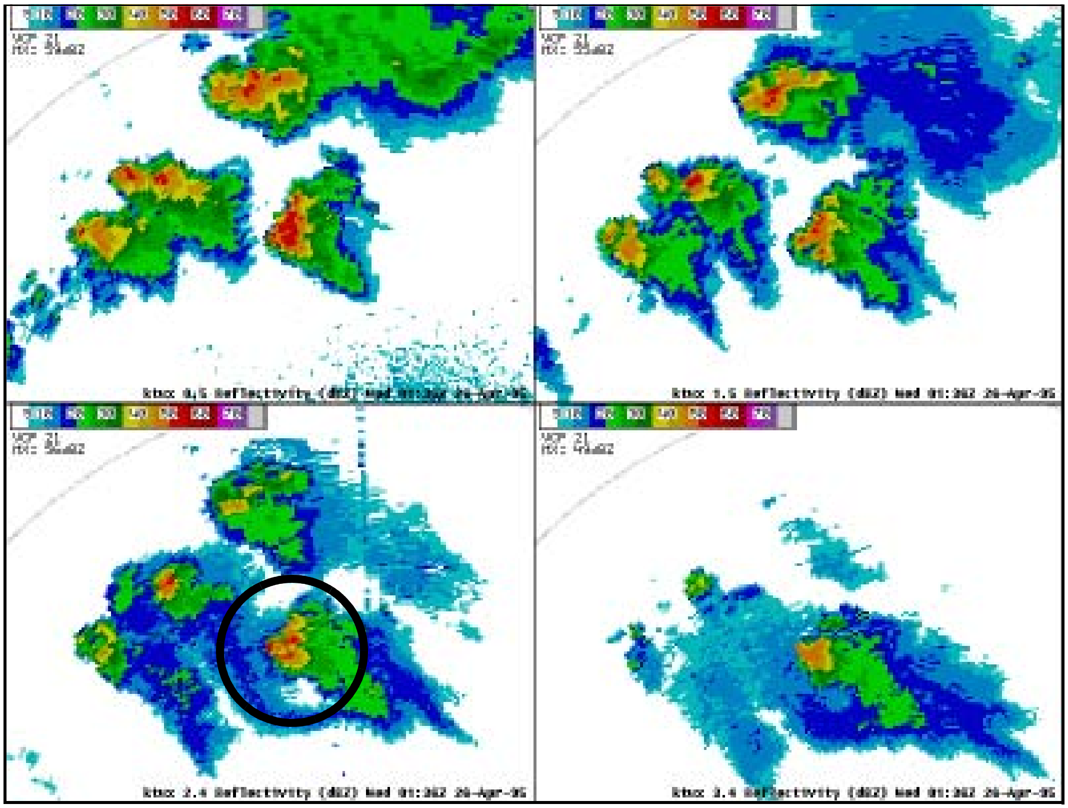


Figure 98. Base Reflectivity four panel display associated with a manual PRF change. Note the small BWER in the 2.4° elevation panel. This storm is at a range of about 70 nm.

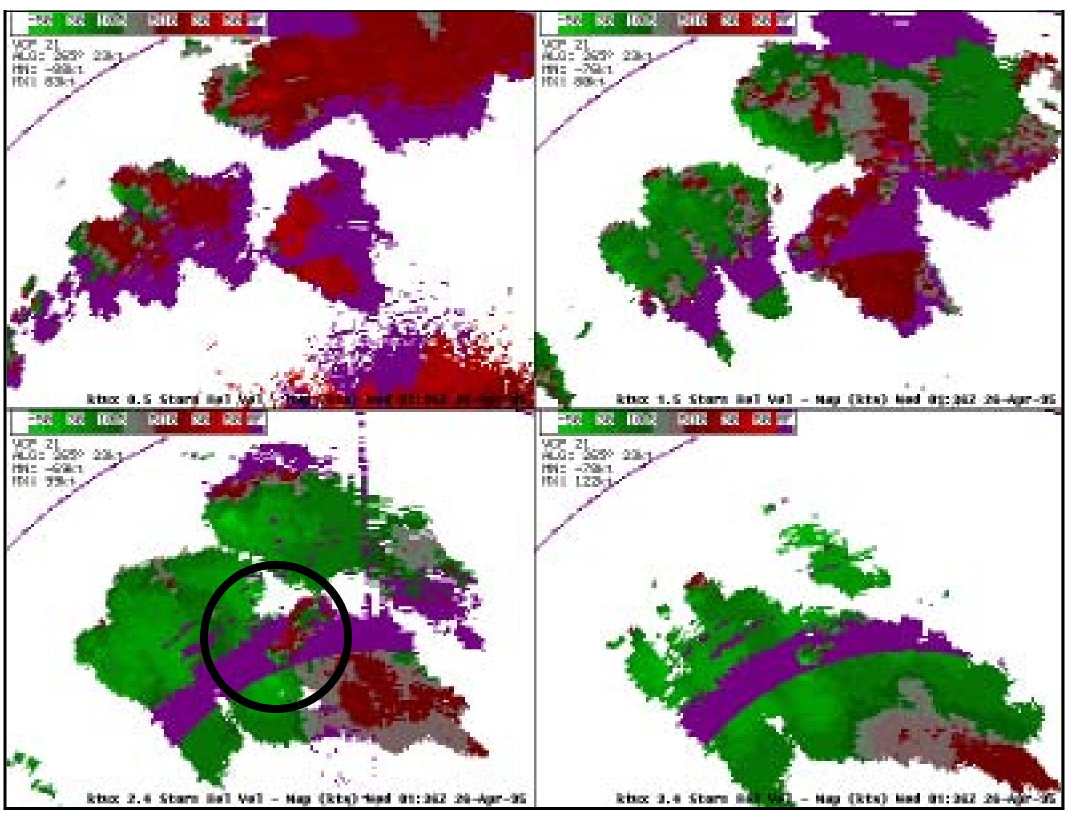


Figure 99. SRM four panel display at 1:36Z. AUTO PRF is on and has selected PRF #8, which results in R_{max} = 63 nm, obscuring the velocity data for the storm of interest.

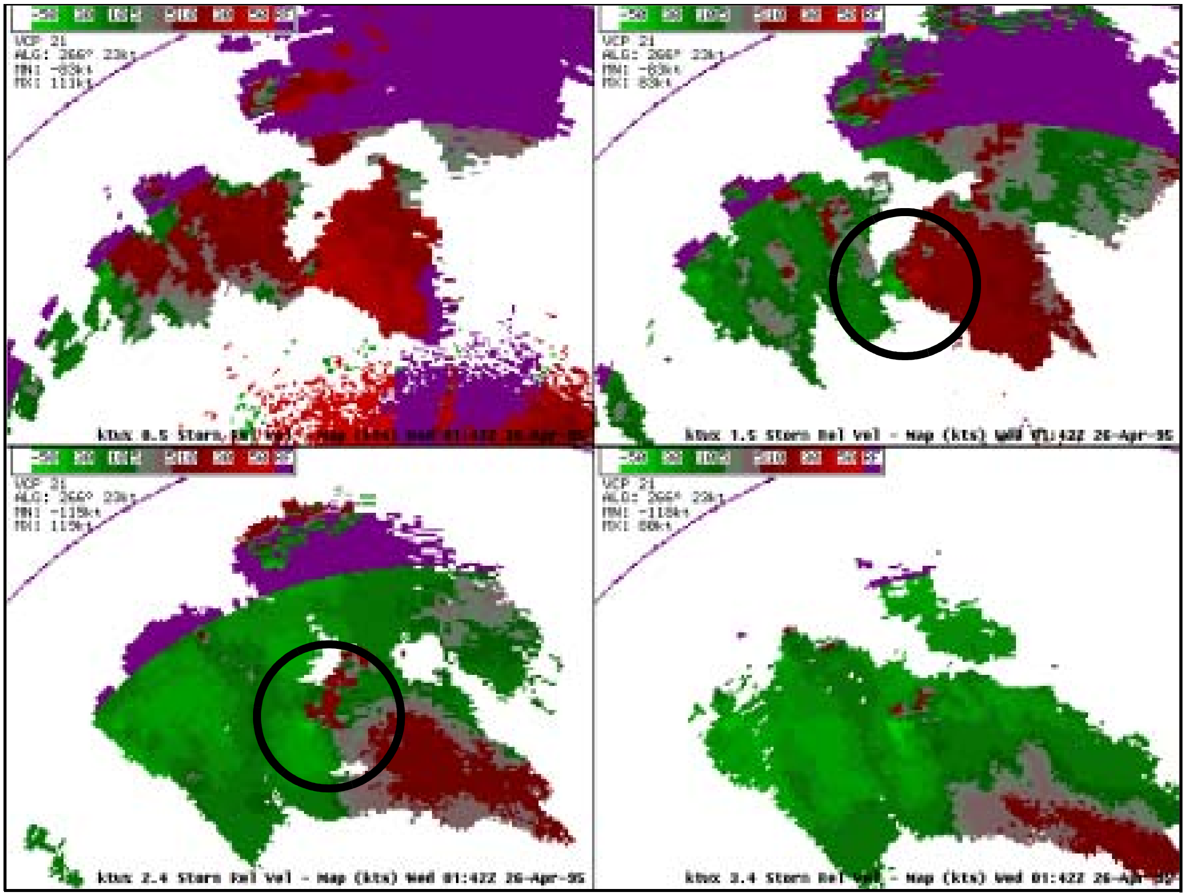


Figure 100. SRM four panel display at 1:42Z. AUTO PRF has been turned off and PRF #4 has been manually selected, resulting in R_{max} = 95 nm. The rotation signature is now apparent, particularly at 1.5° and 2.4°.

Once a manual PRF change is performed for the next volume scan (Figure 100), the rotation features of this storm become apparent.

Mitigation of Data Ambiguities Review Exercises

1. Identify the statement that best describes the "Doppler Dilemma".

a. Increasing radar wavelength increases the radar's ability to detect targets but also increases the potential for velocity aliasing.
b. Decreasing radar wavelength decreases the potential for velocity aliasing, but also decreases the chances of detecting a small target.
c. A high PRF provides a large R_{max} at the expense of a low V_{max} .
d. A low PRF provides a large R_{max} at the expense of a low V_{max} .

2. Describe data characteristics on WSR-88D products that are indicative of

a. Range Folding:

b. Improperly Dealiased Velocities:

c. Ground Clutter Contamination:

d. Anomalous Propagation (AP):

3. Choose one of the following convective situations that would be most conducive for the occurrence of range obscured data (i.e. purple).

a. Five small storms in varying directions from the RDA site.
b. A line of thunderstorms passing over the RDA site.
c. An area of thunderstorms (20 nm wide and 30 nm long) located 40 nm northwest of the RDA site.
d. An intense thunderstorm located 20 nm west of the RDA which has a strong reflectivity gradient on its inflow side.

The following information applies to questions 4, 5 and 6.
CD R_{max} = 62 nm; CS R_{max} = 250 nm

4. Choose the example(s) where echo overlay would occur based on the location (range) of targets A and B when the *CS waveform* is used.

a. A = 54 nm , B = 116 nm
b. A = 36 nm , B = 63 nm
c. A = 47 nm , B = 119 nm
d. none of the above.

5. Choose the example(s) where echo overlay would occur based on the location (range) of targets A and B when the *CD waveform* is used.

a. A = 54 nm, B = 116 nm
b. A = 36 nm, B = 63 nm
c. A = 47 nm, B = 119 nm
d. none of the above.

6. Choose the echo overlay example(s) with the appropriate assignment of velocity (V) and spectrum width (SW) data.

a. Power Ratio A/B = 5.8 dB, TOVER = 5 dB, V & SW assigned to B
b. Power Ratio B/A = 6.3 dB, TOVER = 5 dB, V & SW assigned to B
c. Power Ratio B/A = 9.8 dB, TOVER = 10 dB, V & SW assigned to A
d. Power Ratio A/B = 11.3 dB, TOVER = 10 dB, V & SW assigned to A

7. Choose the correct statement(s) about the adaptable parameter TOVER.

a. The AWIPS operator can change TOVER from 5 dB to 10 dB, causing the amount of range obscured (purple) data to increase.
b. The UCP operator can change TOVER from 10 dB to 5 dB, causing the amount of range obscured (purple) data to decrease.
c. A TOVER setting of 5 dB instead of 10 dB will reduce the amount of range obscured (purple) data.
d. If two targets are overlaid and their relative power ratio is >TOVER, then the strongest storm will be assigned velocity data and the other will be colored purple.

8. Identify the correct statement concerning precipitation estimation and the use of ground clutter suppression.

a. Due to the WSR-88D's high sensitivity, ground clutter is insignificant and does not affect precipitation estimates.
b. Since ground clutter only occurs on the lowest elevation (0.5°), clutter suppression is not needed for the higher elevations close to the RDA.
c. Unnecessary forced suppression will cause an overestimate of precipitation and not enough suppression will cause an underestimate of precipitation.
d. Unnecessary forced suppression will cause an underestimate of precipitation and not enough suppression will cause an overestimate of precipitation.

9. Given V_{max} = 60 knots, and the following WSR-88D's *first guess* velocities, find three possible velocities (aliases) for each case.

a. V_{fg} = -55

b. V_{fg} = +45

10. The RPG HCI operator can change (to a degree) the location of range obscured data by turning the AUTO PRF ________ and then selecting the desired PRF for __________ cuts.

a. off, surveillance
b. on, surveillance
c. off, Doppler
d. on, Doppler

11. Match the strength(s) with the appropriate algorithm.

Algorithm	Strengths
____Range Unfolding	1. Provides accurate velocity data beyond V_{max}.
____Velocity Dealiasing	2. The availability of velocity and spectrum width data beyond the first trip is increased.
____Clutter Suppression	3. Displays accurate velocity data at its appropriate range.
	4. Preserves significant meteorological features (mesocyclones, TVS).
	5. Eliminates false returns from nearby targets such as water towers.
	6. Gets the best possible results despite the Doppler Delimma

12. Match the limitation(s) with the appropriate algorithm.

Algorithm	Limitations
____Range Unfolding	1. Mesocyclone and TVS algorithms may be contaminated.
____Velocity Dealiasing	2. Precipitation estimates can be adversely affected.
____Clutter Suppression	3. Overlaid echoes will be maximized when a squall line is over the RDA.
	4. Performance is affected by a high Spectrum Width and a low Signal to Noise Ratio.
	5. TOVER can only be changed at the RDA.

Review Exercises Answer Key

Precipitation Estimation

1. Is it possible to derive a unique expression relating R to Z? Why or why not?

Not possible:
Both Z and R depend on the dropsize distribution (which is unknown). Z's dependence is on D^6, while R's dependence is on D^3. For any particular Z value, there are many possible Rs, and vice versa, thus their relationship is not one-to-one.

2. Among the possible error sources associated with radar rainfall estimates:

a. Which Z estimate error(s) could cause either an *overestimate* or an *underestimate* of precipitation?

Ground Clutter, Anomalous Propagation, and Incorrect Hardware Calibration

b. List two factors that affect the validity of a Z-R relationship.

1. Variations in the dropsize distribution assumed by the Z-R equation.
2. Mixed precipitation

3. Which of the following are below beam effects that would cause the WSR-88D to *underestimate* rainfall?

b. strong horizontal winds displacing precipitation from an adjacent shower onto the ground below the beam

4. Describe a meteorological event where you would expect rain gage data to be more reliable than radar estimated rainfall.

1. Precipitation that is widespread enough for good sampling by gages, but with a low freezing level that would result in bright band contamination of the radar estimates.
2. Low topped stratiform liquid precipitation that is widespread enough for good sampling by gages, but is at a medium to long range from the radar. Thus the beam is overshooting most of the precipitation.

3. Any good ideas that you may have!

5. Describe a meteorological event where you would expect radar estimated rainfall to be more reliable than rain gage data.

1. Sparsely distributed convective precipitation is unlikely to be sampled well by gages. Assuming the absence of very large hail and that the storms are close enough in range to fill the beam, radar estimates are generally reliable.

2. Any good ideas that you may have!

Signal Processing

1. The WSR-88D is a "coherent" system. What does this mean?

Coherency refers to the ability to determine the phase information for each pulse (in addition to returned power) in order to measure phase changes from one pulse to the next.

2. The Doppler Effect is defined as the change in frequency with which energy reaches a receiver when the receiver and energy source are in motion relative to each other.

a. Does the WSR-88D directly measure a frequency shift? Why or why not?

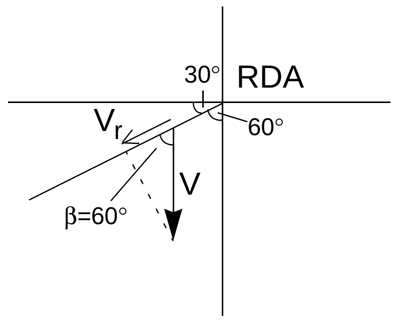
No. F_{dop} is too small compared to the original transmitted frequency to measure directly.

b. What other characteristic of wave energy changes due to target motion? Can the WSR-88D measure this?

The phase of the returned pulse will change if the target is moving.
Yes. The WSR-88D measures phase changes from pulse to pulse.

3. A target is moving due south at 40 knots. It is situated 20 nm to the west-southwest of the RDA (240°/20 nm). What velocity will the radar detect?

$|V_r| = 40\cos 60^\circ = 40(.5) =$ *20 kts*



Target motion is outbound, so velocity is +20 kts

4. For a given range bin, compute the *speed* the WSR-88D will *initially* assign if:

a. V_{max} = 40 knots, pulse pair phase shift is 45°.

$$\frac{|V_r|}{40} = \frac{45^\circ}{180^\circ}$$

$$|V_r| = 40\left(\frac{1}{4}\right) = 10 \text{ kts}$$

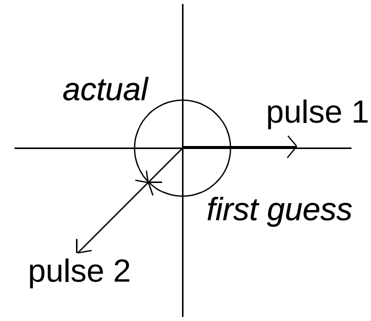
b. V_{max} = 60 knots, pulse pair phase shift is 135°.

$$\frac{|V_r|}{60} = \frac{135^\circ}{180^\circ}$$

$$|V_r| = 60\left(\frac{3}{4}\right) = 45 \text{ kts}$$

c. V_{max} = 60 knots, pulse pair phase shift is 225°.

First guess phase shift is 135°



$$\frac{|V_r|}{60} = \frac{135°}{180°}$$

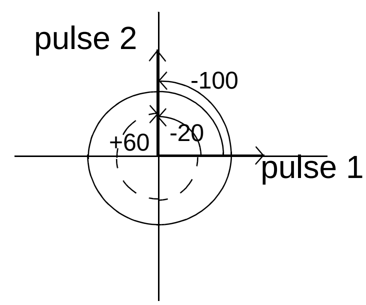
$$|V_r| = 60\left(\frac{3}{4}\right) = 45 \text{ kts}$$

5. Select the degree of phase shift such that a smaller shift is unambiguous and an equal or greater shift is ambiguous.

b. 180°

6. If V_{max} = 40 knots, identify a set of possible radial velocities (knots) if the pulse pair phase shift is 90° counter-clockwise. Hint: Use a technique similar to the one you used in 4c above.

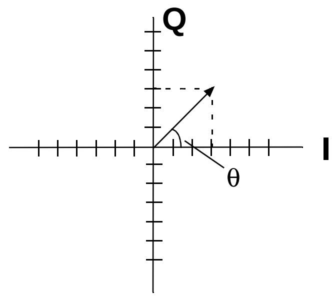
a. -20, -100, +60, +140



You could use the equation $V_p = V_{fg} + n(2V_{max})$, where V_p is a possible velocity, V_{fg} is the first guess velocity, and n=0,±1,±2...
Here, the equation is $V_p = -20 + n(80)$

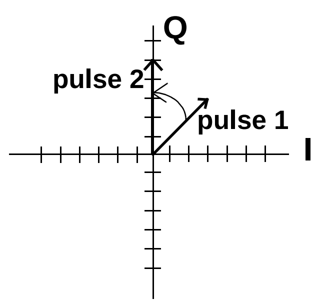
7. If I = 3 and Q = 3, graphically generate a phasor and identify its amplitude and phase (relative to the positive x axis.)

$$A = \sqrt{3^2 + 3^2} = \sqrt{18} = 3\sqrt{2}$$



$\theta = 45°$ by inspection, or $\theta = \mathrm{atan}(1) = 45°$

8. In a range bin, assume I = 3 and Q = 3 from the first pulse, while I = 0 and Q = 5 from the second pulse. If the radar's first guess is correct, is the mean target motion toward or away from the radar?



phasor rotation is counter-clockwise, thus target motion is inbound

Base Data Generation

1. How is dBZ obtained from mean power estimates for each .54 nm resolution range gate?

An average power from 4 successive .13 nm range bins is computed.

$$P_{54} = \frac{P_1 + P_2 + P_3 + P_4}{4}$$

The average power for the .54 nm bin is converted to Z via the radar equation, then Z is converted to dBZ.

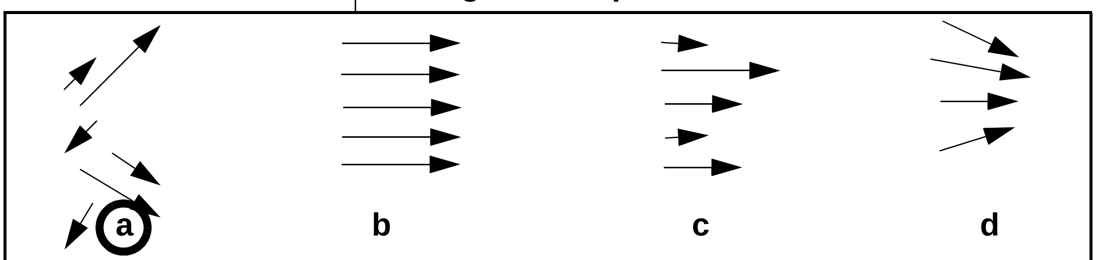
2. The technique employed by the WSR-88D to estimate mean radial velocity is

b. pulse-pair processing

3. How does the WSR-88D estimate spectrum width?

b. Statistical autocorrelation, which measures the variability of the signal over successive pulses.

4. Which of the following four range bins will possess the greatest spectrum width?



5. List the three non-meteorological factors and their effect on the magnitude of spectrum width.

1. Range - Range and Spectrum Width have a direct relationship. As range increases (decreases), spectrum width also increases (decreases).
2. Signal-to-Noise Ratio - The signal strength decreases (approaching the noise level), spectrum width increases.
3. Ground Clutter and AP - Range bin size relative to target size affects spectrum width values. For example, if the range bin encompasses a building and the atmosphere around it, spectrum width values would be higher than if only the building were being sampled.

Mitigation of Data Ambiguities

1. Identify the statement that best describes the "Doppler Dilemma".

d. A low PRF provides a large R_{max} *at the expense of a low* V_{max} *.*

2. Describe data characteristics on WSR-88D products that are indicative of

a. Range Folding: purple on Velocity and Spectrum Width products; elongated echoes at close range on Reflectivity products
b. Velocity Aliasing (i.e. improperly dealiased velocity):spikes/wedges/isolated gates with velocities that do not fit the surrounding data; unrealistic azimuthal shear
c. Ground Clutter Contamination: Reflectivity values are generally high and erratically distributed; Velocity and spectrum width are generally near zero with isolated embedded nonzero values
d. Anomalous Propagation (AP): Reflectivity values are generally high with a mottled appearance; Velocity and spectrum width are generally near zero with isolated embedded nonzero values

3. Choose one of the following convective situations that would be most conducive for the occurrence of data obscuration (i.e. range folding).

b. A line of thunderstorms passing over the RDA site.

The following information applies to questions 4, 5 and 6.

CD R_{max} = 62 nm; CS R_{max} = 250 nm

4. Choose the example(s) where echo overlay would occur based on the location (range) of targets A and B when the *CS waveform* is used.

d. none of the above.

5. Choose the example(s) where echo overlay would occur based on the location (range) of targets A and B when the *CD waveform* is used.

a. A = 54 nm, B = 116 nm

6. Choose the echo overlay example(s) with the appropriate assignment of velocity (V) and spectrum width (SW) data.

b. Power Ratio B/A = 6.3 dB, TOVER = 5 dB, V & SW assigned to B
d. Power Ratio A/B = 11.3 dB, TOVER = 10 dB, V & SW assigned to A

7. Choose the correct statement(s) about the adaptable parameter TOVER.

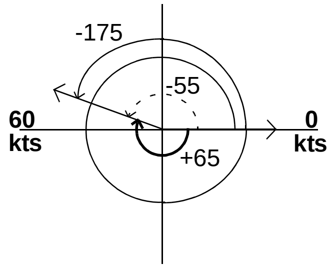
c. A TOVER setting of 5 dB instead of 10 dB will reduce the amount of range obscured (purple) data.
d. If two targets are overlaid and their relative power ratio is >TOVER, then the strongest storm will be assigned velocity data and the other will be colored purple.

8. Identify the correct statement concerning precipitation estimation and the use of ground clutter suppression.

d. Unnecessary forced suppression will cause an underestimate of precipitation and not enough suppression will cause an overestimate of precipitation.

9. Given V_{max} = 60 knots, and the following WSR-88D's *first guess* velocities, find three possible velocities (aliases) for each case.

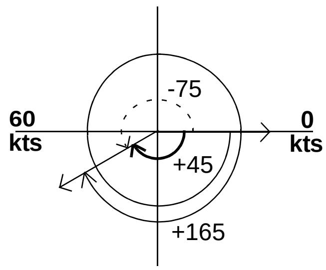
a. V_{fg} = -55



V_p = ..., -175, -55, +65, +185, ...

Could use V_p = -55 + n (120)

b. V_{fg} = +45



Vp = ..., -195, -75, +45, +165, ...

Could use V_p = 45 + n (120)

10. A UCP or ORPG HCI operator can change (to a degree) the location of range obscured data by turning the AUTO PRF ________ and then selecting the desired PRF for __________ cuts.

c. off, Doppler

11. Match the strength(s) with the appropriate algorithm.

Algorithm	Strengths
2,3,6 Range Unfolding	1. Provides accurate velocity data beyond V_{max}.
1,4,6 Velocity Dealiasing	2. The availability of velocity and spectrum width data beyond the first trip is increased.
2,5 Clutter Suppression	3. Displays accurate velocity data at its appropriate range.
	4. Preserves significant meteorological features (mesocyclones, TVS).
	5. Eliminates false returns from nearby targets such as water towers.
	6. Gets the best possible results despite the Doppler Dilemma

12. Match the limitation(s) with the appropriate algorithm.

Algorithm	Limitations
3,5 Range Unfolding	1. Mesocyclone and TVS algorithms may be contaminated.
1,4 Velocity Dealiasing	2. Precipitation estimates can be adversely affected.
2 Clutter Suppression	3. Overlaid echoes will be maximized when a squall line is over the RDA.
	4. Performance is affected by a high Spectrum Width and a low Signal to Noise Ratio.
	5. TOVER can only be changed at the RDA.